Section 5.0 Case Studies

The Western Coal Mining Work Group submitted data and information showing the use of mine models to determine sedimentation and the use of BMPs at existing mine sites in the arid and semiarid western coal region. Summaries of submitted information are presented in this section as three case studies.

5.1 Case Study 1 (Western Coal Mining Work Group, 1999c)

The NMA, as part of the Western Coal Mining Work Group, conducted a study comparing the performance, costs, and benefits of a single model mine site to meet effluent limitations as they currently exist at 40 CFR part 434 versus the proposed option where alternative sediment controls BMPs are used (Western Coal Mining Work Group, 1999c). A representative model mine in the arid and semiarid western United States was developed for the comparison, including contour maps and corresponding hydrologic and soil databases typical of western mines. Original and approximate topography was used to model surface drainage, sediment yield, and soil loss rates from the affected watersheds. Results from RUSLE and SEDCAD modeling were generated for the following three scenarios:

1) Pre-mining Undisturbed Watershed - Modeling of the area prior to any surface preparation, surface disturbance, or mining activities was conducted to characterize background water quality, soil loss rates, and sediment yield. Data were used to establish background standards for BMP system control;

2) Post-mining Reclaimed: Existing Guidelines - A sediment pond focused treatment system was modeled that meets 0.5 mL/L SS at the perimeter outfalls.

3) Post-mining Reclaimed: Sediment Control BMPs - A BMP system focusing on the use of

alternate sediment controls was modeled to provide erosion and sediment control for reclaimed lands seeking to approximate undisturbed background surface drainage volumes and peaks, TSS and SS concentration, soil loss rates, and sediment yields.

Characteristics of the representative model mine area and information used to perform performance and cost evaluations are presented in Table 5a.

Table 5a: Representative Mine Characteristics and Model Input Information

Parameter	Input information
Total Acres	1,188
Actual Disturbed Acres	381.8
Affected Acres	616.7
Unaffected Acres	571.3
Storm Event	10 year – 24 hour
Rainfall	1.8 inches
Soil Type	Sandy clay loam, Loamy sand
Sediment Control BMPs	Manipulation of topography, gradient bench terraces, terrace drains, contour furrows, reclaimed channels, diversion ditches, establishment of permanent vegetation, mulching and detention basins.
# Sedimentation Ponds	3, in series
Types of Surface Conditions	Undisturbed; Spoil, backfilled and graded, topdressed, straw mulched and seeded; Revegetated, 1-3 years Revegetated, 4-8 years
Computer Model Input Information (RUSLE)	Rainfall amount, intensity, frequency and duration; soil moisture conditions, soil types, susceptibility to erosion, eroded particle size distributions, infiltration rates, and soil permeability; vegetative ground cover and evapotranspiration rates

The reclamation area within the representative model mine contained the following surface conditions: areas containing spoil outslopes, and rough and final backfilling and grading, areas where soil resources are being replaced (including topdressing, contour furrowing, mulching, and seeding); and areas with 1-3 years of vegetative growth, or with 4-8 years of more permanent growth. Reclamation area surface conditions also included a final pit undergoing reclamation with the potential for non-process mine drainage to run off the site. This configuration normally represents peak-sediment-yield potential for a reclaimed area during the mining and reclamation process. The reclamation area was positioned within a portion of the watershed, so that drainage from both the reclamation area and the adjacent undisturbed lands were considered in choosing and developing sediment control strategies.

The alternate sediment control BMPs used during reclamation were:

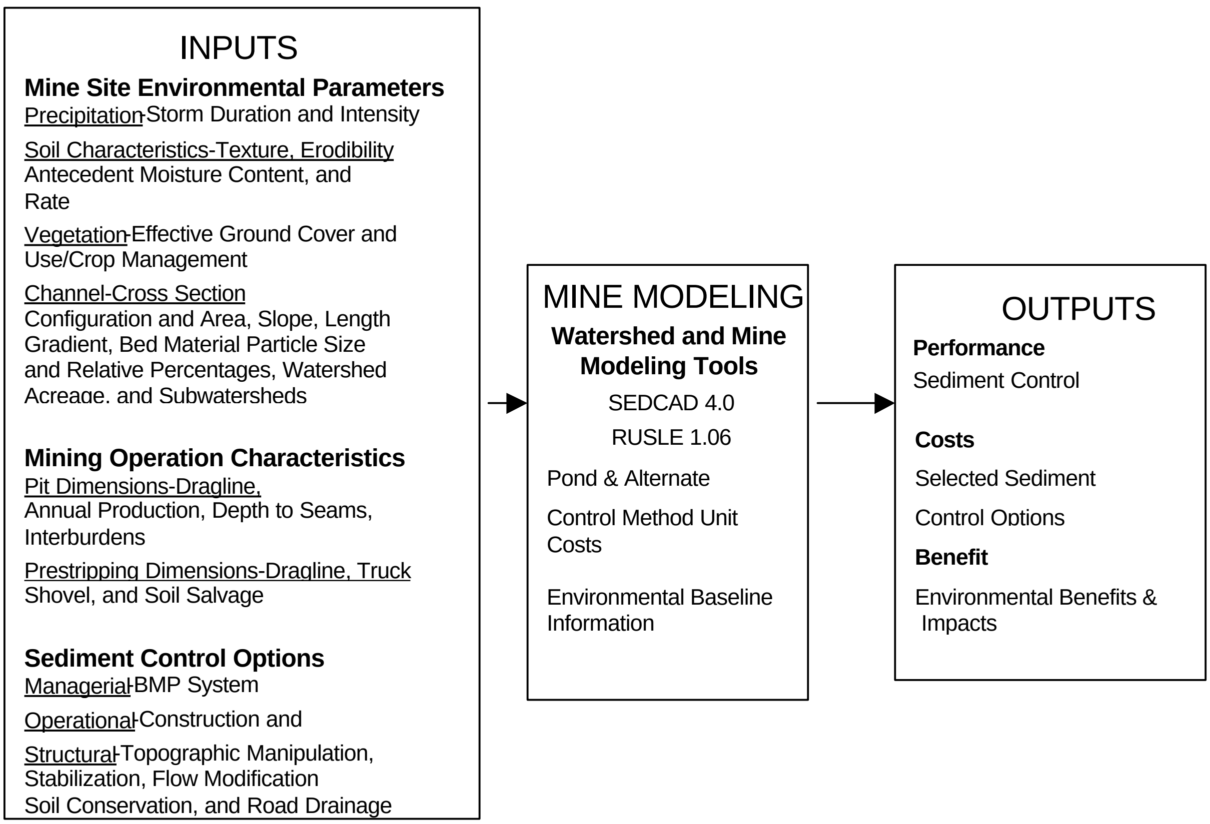
- manipulation of topography to develop more stable slopes
- earthen terraces and berms
- terrace drains
- contour furrows
- diversion ditches
- surface roughening/land imprinting
- sediment detention basins
- revegetation

Reclaimed area topography and the extent of area disturbance were held constant in modeling both reclamation sediment control scenarios. Holding these inputs constant enabled and facilitated the analysis and comparison of model results for soil loss, surface drainage rates, surface drainage volumes, and BMP performance.

5.1.1 Modeling Results

The modeling approach used for this study is shown in Figure 5a. The RUSLE 1.06 and SEDCAD 4.0 models were used to estimate values that characterize site hydrology and sedimentology.

Figure 5a: Mine Model Approach: A Method for Evaluating Erosion and Sediment Control Options (Western Coal Mining Work Group, 1999c)



5.1.1.1 RUSLE 1.06

Annual average soil loss was predicted for two scenarios with the help of RUSLE version 1.06. The two scenarios were for pre-mining (undisturbed) conditions and for post-mining (reclaimed with BMPs). The type of input information for the modeling effort is listed in Table 5b and information input values were based on vegetation, soils, and surface configurations obtained from case study mines and mine permits. Representative data were entered into the RUSLE program to generate sediment loss values. RUSLE input and output data are presented in Appendix D, Tables D-1 through D-5.

For pre-mining, undisturbed conditions, the predicted weighted average annual soil loss was 4.7 tons/acre/yr. According to the Western Coal Mining Work Group, this is a reasonable value for the arid and semiarid coal regions (Western Coal Mining Work Group, 1999c). The weighted average annual soil loss of the reclaimed mine lands was 3.0 tons/acre/yr. Data supporting the weighted average soil loss estimates are presented in Appendix D, Table D-6. The soil loss is slightly lower after reclamation because the BMPs allow for improved infiltration and retention of storm water, and for the growth and establishment of vegetation. Also, implementation of BMPs result in landforms that have been reconstructed to facilitate lower erosion rates and enhanced deposition at down-gradient slope boundaries.

5.1.1.2 SEDCAD 4.0

All sediment and hydrology model results from the mine prior to mining and from the mine after reclamation using BMPs to control sedimentation are similar, whereas the results for the area reclaimed to meet the effluent limitations in 40 CFR part 434 are considerably lower than the pre-mining conditions. The decrease in sediment yield and runoff resulting from compliance with 40 CFR part 434 limits is expected due to the implementation of sedimentation ponds that meet discharge limits by impounding runoff. To avoid potential adverse impacts on the hydrologic and sediment balance, and to maintain the stability of the fluvial system, drainage from the reclamation areas should be as similar to pre-mining drainage as possible. Based on this standard, implementation of BMPs would be a preferred option. Sediment loss, soil loss, and surface runoff flow model results for undisturbed conditions, reclamation areas with sedimentation ponds, and reclamation areas with sediment control BMPs are presented in Table 5b. SEDCAD output for each of the three scenarios is presented in Appendix D.

5.1.2 Cost

The Western Coal Mining Work Group completed an extensive analysis of costs associated with meeting effluent limitations using sedimentation ponds and implementing BMPs under a Western Alkaline Coal Mining subcategory. Cost estimating criteria for sedimentation ponds and BMPs implemented at the model mine were collected from approved mine permit applications, developed from mine records, and estimated using technical resources and industry experience. These unit cost data are presented in detail in NMA's Mine Modeling Report (WCMWG, 1999c).

The model cost assessment was based on capital costs (design, construction, and removal) and operating costs (inspection, maintenance, and operation) associated with BMPs used over the anticipated bonding periods. The bond release period for meeting numerical effluent standards in the arid and semiarid western coal region can be expected to be ten years or longer (Western Coal Mining Work Group, 1999a, Peterson, 1995). With the implementation of alternative sediment control BMPs, reclaimed areas may be eligible for Phase II bond release about five years after they have been successfully revegetated (Western Coal Mining Work Group, 1999a).

Capital and operating reclamation costs, as estimated by the Western Coal Mining Work Group, for both the existing effluent guidelines and the proposed subcategory options are presented in Table 5c. The present value of the reclamation costs over the ten year period (discounting at seven percent) is $ 1,700,000 for the existing guideline and $ 1,028,000 for the proposed subcategory, or a present value total savings of $ 672,000 over ten years. This represents a 39 percent overall reduction in costs, or $1,764 in savings per disturbed acre. The annualized savings is $ 95,000 (annualized at seven percent), or $ 251 annualized savings per acre for the 381 reclaimed acres.

Table 5b: Comparison of Hydrology and Sedimentology Results (modified from Western Coal Mining Work Group, 1999c)

	Pre-Mining Undisturbed Conditions	**Reclaimed to Meet Numerical Limitations[1,2]**	**Reclaimed Under Proposed Subcategory [3]**
RUSLE(V 1.06) Modeling Results			
Soil Loss (tons/acre/year) (Weighted Average)	4.7	NM[4]	3.0
SEDCAD(V 4.0) Modeling Results			
Peak Discharge (cfs) (10 year, 24-hour storm event)	679.09	44.79	601.89
Total Runoff Volume (acre-feet) (10 year, 24-hour storm event)	80.01	48.83	72.93
Sediment (tons) (10 year, 24-hour storm event)	7,004.2	666.1	5,611.1
Sediment (tons/acre) (10 year, 24-hour storm event)	5.9	0.6	4.7
Peak Sediment (mg/L) (10 year, 24-hour storm event)	155,091	28,235	114,800
Peak Settleable Solids (mL/L) (10 year, 24-hour storm)	38.22	0.00	25.86
Settleable Solids (mL/L) (24-hr Volume Weighted) (10 year, 24-hour storm)	17.89	0.00	13.96
Sediment Yield (acre-feet/year) (Average Annual)	8.3	0[5]	6.7

[1] Sediment was controlled with sedimentation ponds.
[2] Assumes ponds are filled to design storage capacity with 3 years of sediment runoff.
[3] Sediment was controlled by alternative sediment control BMPs.
[4] Not measured.
[5] Assumes no sediment is stored in the ponds, and 3 years of annual sediment runoff.

volume is available. SEDCAD 4.0 uses a subroutine that implements a method similar to RUSLE to determine average annual sediment yield. SEDCAD sedimentology input values were taken directly from the RUSLE version 1.06 analysis.

Table 5c: Cost of Existing Guideline Compliance vs. Cost to Implement Alternative Sediment Control BMPs (adapted and revised from WCMWG, 1999c)

Year	Current Effluent Guideline				Proposed Subcategory			
	Capital	Operating	Total	Present Value[1]	Capital	Operating	Total	Present Value[1]
1	$ 975,435	$ 15,384	$ 990,819	$ 990,819	$ 760,816	$ 3,300	$ 764,116	$ 764,116
2	2,720	142,804	145,524	136,004	43,577	103,368	146,944	137,332
3	0	190,181	190,181	166,112	0	59,876	59,876	52,298
4	0	88,956	88,956	72,615	0	77,895	77,895	63,586
5	0	26,231	26,231	20,011	0	14,147	14,147	10,793
6	0	161,999	161,999	115,503	-	-	-	-
7	0	15,269	15,269	10,175	-	-	-	-
8	0	15,269	15,269	9,509	-	-	-	-
9	0	133,377	133,377	77,626	-	-	-	-
10	171,607	15,269	186,876	101,648	-	-	-	-
Total (not discounted)	$1,149,761	$ 804,739	$1,954,501	$1,700,021	$804,393	$258,586	$1,062,979	$1,028,124
Annualized @ 7% over 10 years				$ 242,045				$ 146,382

Annualized Savings	$ 95,663	Present Value Total Savings	$ 671,897
Annualized Savings per Reclamation Acre	$ 251	Present Value Total Savings per Acre	$ 1,764

[1] Discount Rate: 0.07.
[2] Based on 381 disturbed acres.
Costs expressed in 1998 Dollars..

5.2 Case Study 2 (Bridger Coal Company, Jim Bridger Mine)

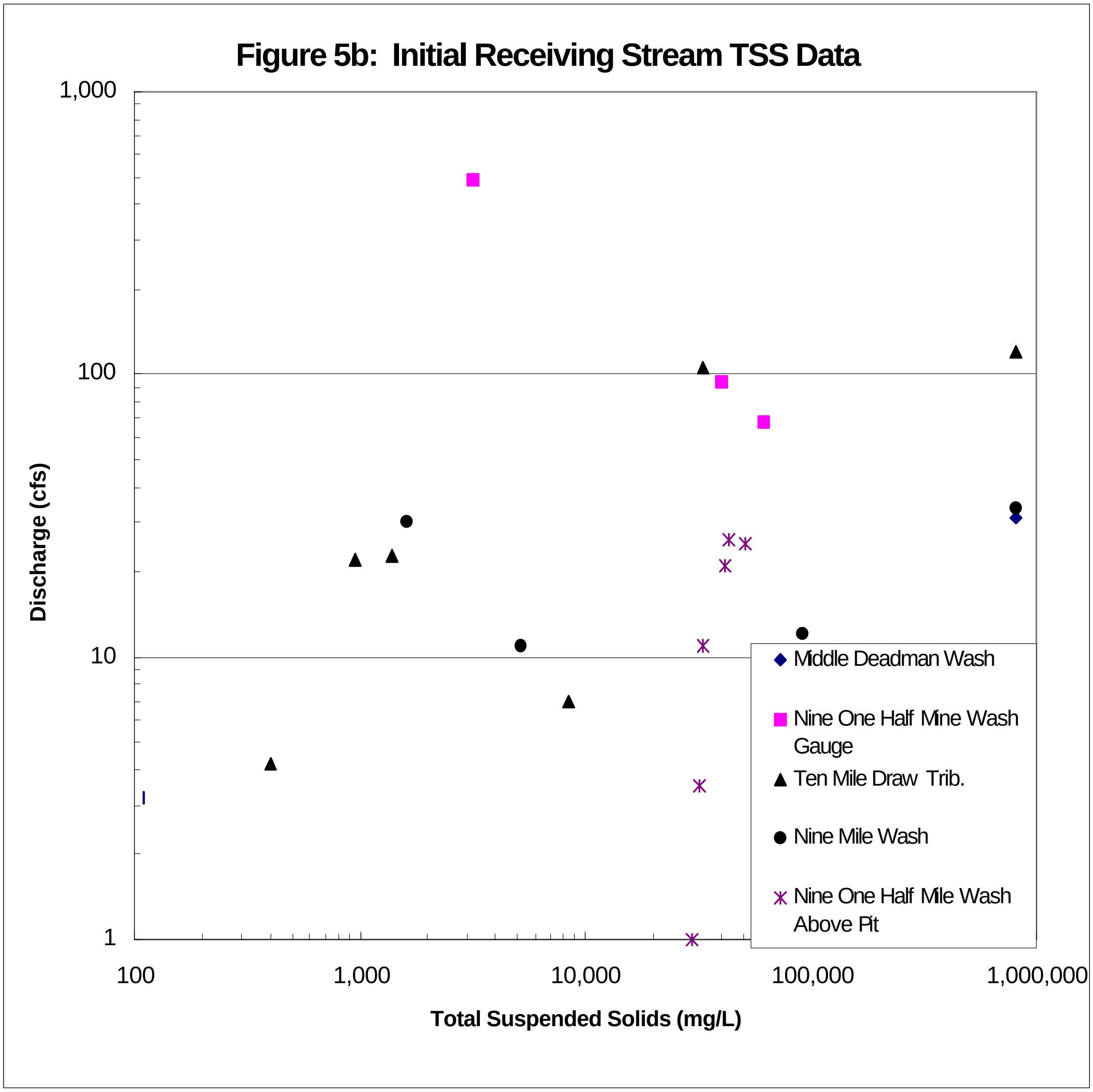
Wyoming Department of Environmental Quality, Land Quality Division Rules and Regulations, Chapter IV, Section 3g(1) states that exemptions to the use of sedimentation ponds may be granted where, by the use of alternative sediment control (ASC) measures, mine drainage will not degrade receiving waters. The Jim Bridger Mine located in southwestern Wyoming, has successfully used ASC measures, in addition to several sediment ponds, to treat disturbed area runoff and prevent degradation of local stream water quality since 1984.

Case Study 2 presents a summary of a Jim Bridger Mine study provided by the Western Coal Mining Work Group (Bridger Coal Company, 1987). Bridger Coal Company began coal production in 1974. The Bridger mine is located in a desert located 28 miles northeast of Rock Springs in southwest Wyoming. Mean annual precipitation is 6-8 inches and the mean frost free period is 100 days. High winds are frequent and evapotranspiration is high. Some soils and spoils are saline or sodic. The local receiving water consists of ephemeral streams.

An experimental practice for a portion of the mine was initiated in 1983 to test the effectiveness of ASC techniques compared to sediment ponds for preventing additional contributions of sediment to receiving streams. The ASC practices became standard in 1987, and are still in use today. The effectiveness of ASC techniques continues to be monitored.

5.2.1 Justification of ASCs

Initial water quality data available for receiving streams are presented in Figure 5b. The data indicate that undisturbed mine area runoff is high in suspended solids. Data from single stage sediment samples show TSS concentrations of 110 to 820,000 mg/L for discharges from 1 to 500 cubic feet per second (cfs). The highest values measured by single stage sediment samples were enriched in coarse sediment by continued circulation during the runoff event. However, values of 800,000 mg/L indicate that sediment transport is high.



Logistical concerns regarding sediment ponds were important in the decision to implement ASC techniques. The extensive mining area and the drainage density would necessitate approximately 200 ponds to control all mining disturbed runoff over the life of the mine. This would entail disturbing over 400 additional acres. Such land disturbance is essentially eliminated by use of ASC techniques.

The benefits of the use of ASCs instead of sediment ponds are:

- Channel degradation below dams, produced by the discharge of unnaturally clear and erosive water, is precluded;
- Additional disturbance due to dam and pond construction is avoided; and
- With the elimination of impoundment storage time, seepage, and evaporation, there is less disruption of natural stream flows.

5.2.2 Description of ASC Techniques

Several techniques are used by the Bridger Coal Company to limit sediment discharge from mined land to background levels (Hargis, 1995). Most of these techniques are appropriate for small drainage areas. Drainage from larger areas can be diverted to the pit floor where it can be stored and used for road watering. The first group of techniques involves preventing the runoff from leaving the disturbed areas. These techniques include:

- berms
- diversion ditches
- toe ditches
- small catchments
- drainage to pit floor via haul roads and ramps

The second group of techniques involves the use of rock check dams or hay bales for the purpose of filtering and temporarily detaining runoff water until some of its sediment load settles. Check dam size is determined by using the SEDIMOT II computer program. These materials are used a short distance downstream from the disturbed land. They are installed before soil removal and maintained while the disturbed drainage area is unstable.

A third group of techniques involves appropriate mine land reclamation practices and includes:

- prudent geomorphic design
- reconstruction of complex slopes
- restoration of drainage density
- roughening of soil surface
- mulching
- contour farming

• timely establishment of permanent vegetative cover

Bridger Coal Company continuously evaluates the effectiveness of sediment control technologies that are in place at this site as well as the predicted effectiveness of additional techniques, and modifies the ASC plan appropriately when necessary.

5.2.3 ASC Design

In order to determine the most appropriate ASC techniques for each mining area, Bridger Coal Co. used the computer models SEDIMOT II and SEDCAD. These models allow evaluation of disturbed area runoff prior to the disturbance and simulate the various ASCs. These models also allow the determination of ASC size and location necessary to reduce the sediment discharge to levels below the receiving stream water quality. Once an ASC plan has been designed and implemented, a monitoring program is then used to determine the effectiveness of the control techniques and record water quality degradation, should any occur.

Prior to the original permit application at this site, surface water quality data showed that TSS was the only parameter that was consistently high, and was, therefore, of concern to in stream water quality. This data is presented in Table 5d. For this reason, and because of the importance of sediment transport in fluvial systems, TSS is the primary water quality parameter considered in design of ASC techniques.

Table 5d: Premining Surface Water Quality Data

Site	Type	Date	Iron (mg/L)	Manganese (mg/L)	Field pH	TSS (mg/L)	Discharge (cfs)
BCTR	PD	04/14/80	1.47	0.044	7.20	411.0	-
BCTR	PD	05/15/80	1.32	0.048	9.00	303.0	-
L10MD	SC	01/17/80	1.42	0.190	-	182.0	-
L10MD	SC	04/14/80	0.52	0.033	-	1240.0	-
MDW	SC	06/17/80	475.00	7.600	-	21750.0	-

Site	Type	Date	Iron (mg/L)	Manganese (mg/L)	Field pH	TSS (mg/L)	Discharge (cfs)
MDW	SC	05/14/80	1.08	0.449	-	66152.0	-
MDW	SS	06/17/80	475.00	7.600	-	21750.0	-
UDW	SS	03/17/80	1.15	0.430	7.80	1672.0	-
U10MD	SC	04/26/79	0.55	0.180	-	24.0	-
U10MD	SC	05/31/79	0.47	0.050	8.40	40.0	-
U10MD	SC	08/22/79	4.76	0.120	7.30	79.0	-
U10MD	SC	10/24/79	0.06	-	8.00	52.0	-
U10MD	SC	03/11/80	0.16	0.064	7.70	68.0	-
U10MD	SC	04/14/80	0.21	0.029	8.30	916.0	-
U10MD	SS	03/19/81	1.24	0.190	-	56.0	-
10MDT	SC	04/16/80	2.78	0.090	-	8728.0	-
10MDT	SC	06/17/80	165.00	3.200	-	8141.0	18.0
10MDT	SS	03/13/80	164.00	2.100	-	1532.0	28.0
10MDT	SS	04/16/80	180.65	2.715	-	8728.0	1.0
10MR3	PD	04/26/79	2.40	0.050	7.80	68.0	-
10MR3	PD	08/22/79	23.60	0.260	8.20	275.0	-
10MR3	PD	09/25/79	32.00	0.440	6.00	816.0	-
10MR3	PD	04/16/80	0.56	0.210	8.80	71.0	-
10MR3	PD	05/15/80	0.50	0.200	7.30	418.0	-
10MR3	PD	06/18/80	4.12	0.075	7.90	37.0	-
10MR3	PD	07/10/80	1.27	0.130	7.50	65.0	-
10MR3	PD	08/04/80	3.04	0.385	7.20	180.0	-
10MR3	PD	09/05/80	4.20	0.410	7.40	368.0	-
10MR3	PD	10/02/80	1.42	0.020	8.30	438.0	-
10MR3	PD	11/06/80	3.15	0.332	8.75	-	-
10MR4	PD	04/26/79	31.00	0.370	-	620.0	-
10MR4	PD	08/22/79	16.00	0.190	7.80	348.0	-
10MR4	PD	09/25/79	1.67	0.270	6.20	30.0	-
10MR4	PD	10/24/79	1.59	0.000	7.40	36.0	-

Site	Type	Date	Iron (mg/L)	Manganese (mg/L)	Field pH	TSS (mg/L)	Discharge (cfs)
10MR4	PD	04/14/80	0.47	0.120	7.40	19.5	-
10MR4	SC	05/15/80	0.46	0.210	7.50	715.0	-
10MR4	SS	06/18/80	55.50	1.570	6.80	1700.0	-
9.5MD	SS	04/15/80	0.34	0.450	-	4516.0	-
9.5MD	SS	08/22/79	1470.00	22.100	-	3211.0	-
9.5MW	SC	07/29/81	936.00	-	-	61600.0	72.0
9.5MW	SS	09/15/81	930.00	-	-	38700.0	104.0
9MW	SS	06/17/80	140.00	3.500	-	11660.0	-
9MW	SS	08/21/79	520.00	12.100	-	5373.0	-
9MW	SS	03/08/80	42.20	0.920	-	1768.0	19.7
9MW	SS	07/15/81	1050.00	-	-	93600.0	-

PD = Pond; SC = Stream Channels; and SS = Sediment Sampling Stations.

In the SEDIMOT II and SEDCAD models, the SCS curve number is used for flow runoff calculations; the Modified Universal Soil Loss Equation (MUSLE) is used for soil loss calculations; the Muskingum method is used to route water flow; Williams Model I is used to route sediment in channels; and Yang's unit stream power equation is used to route sediment overland. Application of these models allows increased temporal and spatial variability to be incorporated into the analysis, and allows for channel segments and subwatershed areas to be specified to simulate individual contributions to the total basin output.

For this site, a database containing TSS concentrations in a small ephemeral stream during pre-mining, undisturbed conditions existed prior to the initial ASC application submittal. Data from this database are presented in Table 5e. From this database, a design TSS input value for the SEDIMOT II/SEDCAD simulations was calculated. The arithmetic average of these data (30,000 mg/L) was used as a design criterion to determine the location and size of the ASC structures. Preferably, disturbed area runoff should be near or below the mean TSS concentration of the observed data (30,000 mg/L). The actual impact of the mine runoff on the receiving stream water quality was determined from the data collected from the ASC monitoring program.

Table 5e: Existing Database, Undisturbed TSS Concentration Data

Location	Date	TSS (mg/L)	Peak Monthly Flow (cfs)	10-Yr.-24-hr. Peak Discharge (cfs)
Nine Mile Wash	08/21/79	5,373.0	13.0	1,646.0
	03/08/80	1,768.0	35.4	
	10/05/80	37,700.0	50.4	
	10/05/80	22,640.0	50.4	
	07/15/81	93,600.0	12.0	
	08/09/82	34,050.0	55.0	
9.5 Mile Wash @ Crest Gage	08/22/79	3,211.0	375.0	625.0
	07/29/81	61,600.0	72.0	
	09/15/81	38,700.0	104.0	
	08/05/82	95,700.0	120.0	
Middle Deadman Wash	5/14/80	66,152.0	5.0	887.0
	06/17/80	21,750.0	8.0	
9.5 Mile Wash @ Temp. Recording Sta.	09/14/82	53,540.0	27.0	
		44,500.0	28.0	
		42,920.0	22.0	
		34,660.0	11.0	
		32,780.0	4.0	
		29,420.0	1.0	
	9/24/82	3,155.0	NA[1]	
		17,000.0	NA[1]	
		20,300.0	NA[1]	
		15,540.0	NA[1]	
		24,840.0	NA[1]	
		20,490.0	NA[1]	
		17,150.0	NA[1]	
		19,900.0	NA[1]	
		16,120.0	NA[1]	
		20,020.0	NA[1]	
		14,670.0	NA[1]	
		13,340.0	NA[1]	
		36,860.0	NA[1]	
		8,160.0	NA[1]	
		14,800.0	NA[1]	
		Average = 29,770	**(Round to 30,000)**	

[1] Not available, hydrograph not recorded.

The actual ASCs selected differ for each reclaimed area and are determined by site specific analysis. As part of this analysis, the company uses SEDIMOT II/SEDCAD to model the effects of seven ASC techniques, simulated in sequence as presented in Table 5f. The sequence is determined by experience with ASC effectiveness in reducing sediment discharges.

Table 5f: Order of Simulation of Sediment Control Best Management Practices

Order of Implementation in Design	Sediment Control Technique
1	Rock Check Dams
2	Interceptor Ditch (Contour Ditch)
3	Contour Berms
4	Vegetative Buffer Strip
5	Toe Drain Ditch
6	Temporary Barrier
7	Benches

5.2.4 Monitoring Program

Monitoring is conducted during runoff events between May 1 and September 30 (when temperatures are above freezing). Each monitoring station is serviced generally after each storm, and at least once per month, from May through September. In addition, checks are performed every two weeks from May through September.

Through the first three mining periods, eight paired watersheds (four pairs) and one control station were equipped with automatic pump samplers and manometers. Each watershed pair consisted of one disturbed watershed treated with ASCs and an undisturbed watershed. The nine sampling stations were:

SWPS-2	Station SWPS-2 was a control watershed location on a tributary of Deadman Wash. This station was impacted by mining in 1990 and decommissioned in 1991. However, no data were collected because very little runoff was generated by the small storms that occurred in the watershed since the station was installed.
SWPS-3	Station SWPS-3 is the upstream receiving stream station located near the upper mining limit. SWPS-3 is located on Deadman Wash and provides pre-mining, undisturbed data.
SWPS-4	Station SWPS-4 was located on Deadman Wash, downstream from SWPS-3. SWPS-4 was the disturbed watershed paired with SWPS-3 during the experimental period (1984-1987). The site was decommissioned in 1987 and mined through in 1988.
SWPS-7	Station SWPS-7 was located on Deadman Wash, just above the outlet of the SWPS-8 watershed. SWPS-7 was the undisturbed watershed paired with SWPS-8 during the experimental period (1984-1987). The site was decommissioned in 1987.
SWPS-8	Station SWPS-8 monitors a disturbed watershed on a tributary of Deadman Wash. SWPS-8 is located approximately 1,000 feet upstream from Deadman Wash.
SWPS-9	Station SWPS-9 is a Deadman Wash downstream receiving station that is located approximately 100 feet upstream from the confluence of Deadman Wash and Nine Mile Draw.
SWPS-10	Station SWPS-10 is a disturbed watershed location on Nine Mile Draw. This location is located approximately 300 feet upstream from the confluence of Nine Mile Draw and Deadman Wash.
SWPS-13	Station SWPS-13 is upstream from the pit and represents the receiving stream.
SWPS-14	Station SWPS-14 is downstream of all mining disturbance in the Ten Mile Draw drainage basin.

5.2.5 Data Reduction

During the first permit term, the discharge monitoring data were reduced using standard U.S. Geological Survey (USGS) procedures for continuous sediment and water stage data. The reduced data were then analyzed using either a covariance test or a modified Student's t - test in order to determine whether degradation occurred in the receiving stream as a result of the disturbed area runoff.

During the second and all subsequent permit terms, the data reduction procedure followed Porterfield (1972). This procedure is summarized as follows:

1. The stage recorder chart is adjusted for any pen, data, or time corrections that are applicable.
2. Discrete sediment sample data are used to construct a continuous temporal sediment concentration graph on the same scale as the flow record.
3. Water stage and sediment graphs are subdivided by mid-intervals into discrete water discharge, sediment concentration, and sediment discharge values. In order to avoid biasing the data in subsequent analyses, equal time intervals are used for the disturbed stream and receiving stream subdivisions.
4. The subdivided water discharge and sediment discharge data are used to calculate storm sediment yields in tons per acre and storm water yields in acre-feet per square mile.
5. A log-log data plot of all monitoring stations is prepared with storm sediment yield plotted against storm water yield.

5.2.6 Data Analysis

Once data have been reduced they are analyzed to determine if degradation has occurred (i.e., sediment yield has increased over background conditions). During the first permit term (1984-1987), the discharge monitoring data were reduced using standard USGS procedures for continuous sediment and water stage data. The allowable TSS change criteria initially were based on a statistical comparison of storm sediment concentrations in the receiving stream before and after addition of the disturbed area runoff. Sediment data were analyzed with either a covariance test (for multiple pairs), or a modified Student's t - test (for a single pair of TSS data points) in order to determine whether degradation of the receiving stream (Deadman Wash) by the disturbed area runoff occurred. Since no degradation had been detected in over 65 storms, ASC control techniques were determined to be successful.

A simpler method for assessing differences in TSS concentrations between paired watersheds was approved for the second and subsequent terms of the permit. First, instantaneous TSS concentrations and flow rates are collected at adequate intervals to accurately calculate storm water and sediment yield. An example of reduced storm yield data is presented in Table 5g.

Table 5g: Example Water and Sediment Yield Data (1984 - 1998)

Station	Date	Stream Type	Water Yield (acre-ft/mi^2)	Sediment Yield (tons/acre)
SWPS-3	7/31/84	Receiving	1.477484022	0.050618459
SWPS-3	6/25/85	Receiving	0.005176922	0.0000418
SWPS-3	7/18/85	Receiving	0.031431064	0.00089235
SWPS-3	7/23/85	Receiving	0.11673182	0.005699971
SWPS-3	7/30/85	Receiving	0.080180455	0.001962336
SWPS-3	4/24/86	Receiving	0.002708907	0.0000293
SWPS-3	5/8/86	Receiving	0.009636635	0.0000606
SWPS-3	7/4/86	Receiving	0.010107986	0.0007701
SWPS-3	8/29/86	Receiving	0.003897468	0.00012434
SWPS-3	9/24/86	Receiving	0.001839712	0.0000272
SWPS-3	9/26/86	Receiving	0.002459572	0.0000167
SWPS-3	9/27/86	Receiving	0.001592364	0.000009
SWPS-3	5/29/87	Receiving	0.02346527	0.00057052
SWPS-3	5/30/87	Receiving	0.002834567	0.0000439
SWPS-3	6/9/87	Receiving	0.025076508	0.0005538
SWPS-3	9/3/87	Receiving	0.007832187	0.00028004
SWPS-3	9/4/87	Receiving	0.021765622	0.00035631
SWPS-3	7/12/89	Receiving	0.00843516	0.00030093
SWPS-3	9/19/89	Receiving	0.010161131	0.00017763
SWPS-3	8/21/90	Receiving	0.001368857	0.000008
SWPS-3	5/22/91	Receiving	0.011213602	0.00036676
SWPS-3	6/1/91	Receiving	0.519122156	0.012856543
SWPS-3	6/13/91	Receiving	0.03358617	0.00099266
SWPS-3	7/25/91	Receiving	0.12759526	0.00192681
SWPS-3	9/9/91	Receiving	0.034409669	0.001002066
SWPS-3	9/29/91	Receiving	0.13113313	0.004085589
SWPS-3	7/11/92	Receiving	0.333143	0.004893302
SWPS-3	7/21/92	Receiving	0.063889	0.001587215
SWPS-3	6/3/93	Receiving	0.094653	0.00055171
SWPS-3	6/17/93	Receiving	0.16531	0.00061545

Station	Date	Stream Type	Water Yield (acre-ft/mi^2)	Sediment Yield (tons/acre)
SWPS-3	6/26/93	Receiving	0.14757	0.004199484
SWPS-3	9/12/94	Receiving	0.005984	0.00011808
SWPS-3	5/25/96	Receiving	0.014834	0.0000742
SWPS-3	9/8/95	Receiving	0.090383	0.002519272
SWPS-4	7/31/84	Disturbed	1.281434215	0.059088767
SWPS-4	7/18/85	Disturbed	0.038092331	0.00066273
SWPS-4	7/23/85	Disturbed	0.089620306	0.006017068
SWPS-4	7/30/85	Disturbed	1.315367177	0.037101028
SWPS-4	7/4/86	Disturbed	0.017723258	0.00096693
SWPS-4	9/3/87	Disturbed	0.036651076	0.002640955
SWPS-4	9/4/87	Disturbed	0.051385958	0.001527354
SWPS-7	7/31/84	Receiving	0.883773652	0.03245597
SWPS-7	8/6/84	Receiving	0.018663956	0.00091022
SWPS-7	8/18/84	Receiving	0.008212654	0.00029353
SWPS-7	9/6/84	Receiving	0.078186652	0.002446697
SWPS-7	7/18/85	Receiving	0.026335062	0.00052174
SWPS-7	7/20/85	Receiving	0.037043061	0.001852661
SWPS-7	7/23/85	Receiving	0.080330902	0.004302842
SWPS-7	7/30/85	Receiving	1.64197228	0.036970469
SWPS-7	7/4/86	Receiving	0.031810992	0.001072226
SWPS-7	5/29/87	Receiving	0.049678773	0.002706261
SWPS-7	6/9/87	Receiving	0.010749402	0.00050693
SWPS-7	9/3/87	Receiving	0.017177596	0.0008806
SWPS-7	9/4/87	Receiving	0.06342408	0.001558256
SWPS-8	7/9/84	Disturbed	0.864063707	0.039664882
SWPS-8	7/31/84	Disturbed	2.989430677	0.346925851
SWPS-8	8/6/84	Disturbed	1.377395402	0.128622236
SWPS-8	8/18/84	Disturbed	0.65060337	0.029959021
SWPS-8	9/6/84	Disturbed	2.053912776	0.0679606
SWPS-8	7/30/85	Disturbed	7.646761495	0.747331783
SWPS-8	5/29/87	Disturbed	0.942419621	0.034361881
SWPS-8	7/23/89	Disturbed	16.7603059	0.85378317
SWPS-8	9/18/89	Disturbed	1.953010004	0.05122973
SWPS-8	7/20/90	Disturbed	0.756138294	0.017944103
SWPS-8	9/4/90	Disturbed	24.80262338	0.729661636
SWPS-8	7/12/92	Disturbed	3.338507	0.040114953
SWPS-8	7/21/92	Disturbed	0.386208	0.03935179
SWPS-8	6/7/93	Disturbed	1.28865	0.008883994
SWPS-8	7/26/93	Disturbed	2.903206	0.129072306
SWPS-8	9/7/95	Disturbed	3.5058	0.220394066
SWPS-8	9/21/97	Disturbed	1.292154	0.048861472
SWPS-9	7/31/84	Receiving	0.968139808	0.066406744

Station	Date	Stream Type	Water Yield (acre-ft/mi^2)	Sediment Yield (tons/acre)
SWPS-9	8/6/84	Receiving	0.030162507	0.001983688
SWPS-9	9/6/84	Receiving	0.340016234	0.023758994
SWPS-9	7/18/85	Receiving	0.037446771	0.00087062
SWPS-9	7/20/85	Receiving	0.393764689	0.024798275
SWPS-9	7/23/85	Receiving	0.145318019	0.005443206
SWPS-9	7/30/85	Receiving	2.115498217	0.129639835
SWPS-9	6/9/87	Receiving	0.046868004	0.003246825
SWPS-9	9/19/89	Receiving	0.60228965	0.013080951
SWPS-9	8/4/90	Receiving	0.377490999	0.009658689
SWPS-9	5/15/91	Receiving	0.524044071	0.00476637
SWPS-9	8/4/91	Receiving	0.137681387	0.003731229
SWPS-9	9/7/95	Receiving	1.280506	0.037841673
SWPS-9	9/21/97	Receiving	0.808959	0.036334021
SWPS-9	7/24/98	Receiving	0.233039	0.006275786
SWPS-9	7/25/98	Receiving	0.114991	0.003876858
SWPS-9	8/3/98	Receiving	0.070143	0.003449813
SWPS-10	7/21/84	Disturbed	0.027840712	0.00060744
SWPS-10	7/31/84	Disturbed	1.273303295	0.063190439
SWPS-10	8/1/84	Disturbed	0.059938324	0.001226025
SWPS-10	8/4/84	Disturbed	0.024953331	0.00072447
SWPS-10	8/23/84	Disturbed	0.187992353	0.004881808
SWPS-10	9/6/84	Disturbed	1.220188727	0.024843723
SWPS-10	9/13/84	Disturbed	0.29014207	0.01063298
SWPS-10	9/21/84	Disturbed	0.086033362	0.00068546
SWPS-10	6/25/85	Disturbed	0.225655459	0.004346816
SWPS-10	7/18/85	Disturbed	0.088624058	0.003332559
SWPS-10	7/20/85	Disturbed	1.274837051	0.057595307
SWPS-10	7/23/85	Disturbed	0.490645525	0.016545764
SWPS-10	7/30/85	Disturbed	1.892771051	0.07519991
SWPS-10	9/2/85	Disturbed	0.301326036	0.014233035
SWPS-10	9/11/85	Disturbed	0.224095213	0.004608739
SWPS-10	9/19/85	Disturbed	0.285482526	0.00433567
SWPS-10	7/4/86	Disturbed	0.065318389	0.003137509
SWPS-10	7/9/86	Disturbed	0.03566578	0.00096967
SWPS-10	9/8/86	Disturbed	0.040836576	0.001148005
SWPS-10	7/11/87	Disturbed	0.045726581	0.00097525
SWPS-10	9/4/87	Disturbed	1.077011708	0.01375377
SWPS-10	7/26/88	Disturbed	0.345285	0.023645
SWPS-10	8/3/88	Disturbed	0.881732	0.034852
SWPS-10	7/12/89	Disturbed	10.2879986	0.4594194
SWPS-10	7/23/89	Disturbed	9.266459047	0.493653359
SWPS-10	9/18/89	Disturbed	0.204264997	0.007283703

Station	Date	Stream Type	Water Yield (acre-ft/mi^2)	Sediment Yield (tons/acre)
SWPS-10	9/19/89	Disturbed	1.70304627	0.026197923
SWPS-10	9/20/89	Disturbed	0.350679062	0.004809361
SWPS-10	7/20/90	Disturbed	0.005629069	0.00015047
SWPS-10	7/24/90	Disturbed	6.277730829	0.26287646
SWPS-10	8/4/90	Disturbed	0.207790781	0.010900476
SWPS-10	8/30/90	Disturbed	1.216872212	0.064923592
SWPS-10	6/1/91	Disturbed	1.261933901	0.079357249
SWPS-10	6/13/91	Disturbed	0.289479827	0.013982257
SWPS-10	8/27/91	Disturbed	0.068529	0.00109785
SWPS-10	9/9/91	Disturbed	0.040127	0.00635304
SWPS-10	9/29/91	Disturbed	0.019763991	0.00064645
SWPS-10	6/3/93	Disturbed	0.38052	0.006587097
SWPS-10	6/17/93	Disturbed	0.820869	0.007857705
SWPS-10	7/26/93	Disturbed	0.576255	0.019192863
SWPS-10	8/11/93	Disturbed	0.077249	0.002496633
SWPS-10	9/17/93	Disturbed	0.030802	0.00046812
SWPS-10	9/18/93	Disturbed	1.749732	0.02525054
SWPS-10	9/8/95	Disturbed	0.155225	0.004313379
SWPS-10	9/21/97	Disturbed	2.60624	0.107340165
SWPS-13	9/21/97	Receiving	9.156198	0.139136745
SWPS-14	9/21/97	Disturbed	0.039105	0.001971105
SWPS-14	7/29/98	Disturbed	0.009494	0.00032269

Next, the 95% prediction bands confining the regression equation $y = 0.0339(x)^{1.0925}$ are calculated using Equation 5a developed for predicting any value of "y" for a given "x" (Kleinbaum, 1978). Unit water and sediment yield are plotted with the 95% prediction intervals in Figure 5c and a graphical comparison is made of the individual storm sediment yield relative to the general trend. Any points (storms) which fall inside the 95% prediction interval show that no significant variation from background sediment yield has occurred. If the disturbed monitoring station points (storms) plot above the predicted interval, degradation has technically occurred and mitigation measures are immediately taken. No unit sediment yields, of storms less than a 10-year, 24-hour event, plotted outside of the confidence bands between 1984 and 1998.

Equation 5a

$$y_0 = \overline{Y} + B_1(X_0 - \overline{X}) \pm t_{(n-2,\ 1-\alpha/2)} * S_{y/x} * \sqrt{\left(1 + \frac{1}{n} + \frac{(X_0 - \overline{X})^2}{(n-1) * S_X^2}\right)}$$

Where:

$\overline{Y}$ = Mean of Y values

$\overline{X}$ = Mean of X values

B_1 = Coefficient of Regression Equation
X_0 = Value in Question
y_0 = Value in Question
$t_{(n-2, 1-\alpha/2)}$ = t statistic
n = Number of values
S_x^2 = Variance of x values

$$S_{y/x} = \sqrt{\left(\frac{n-1}{n-2}\right) * (S_y^2 - (B_1^2 * S_X^2))}$$

Where:

S_y^2 = Variance of Y values
n = Number of values
S_x^2 = Variance of X values
B_1 = Coefficient of Regression Equation

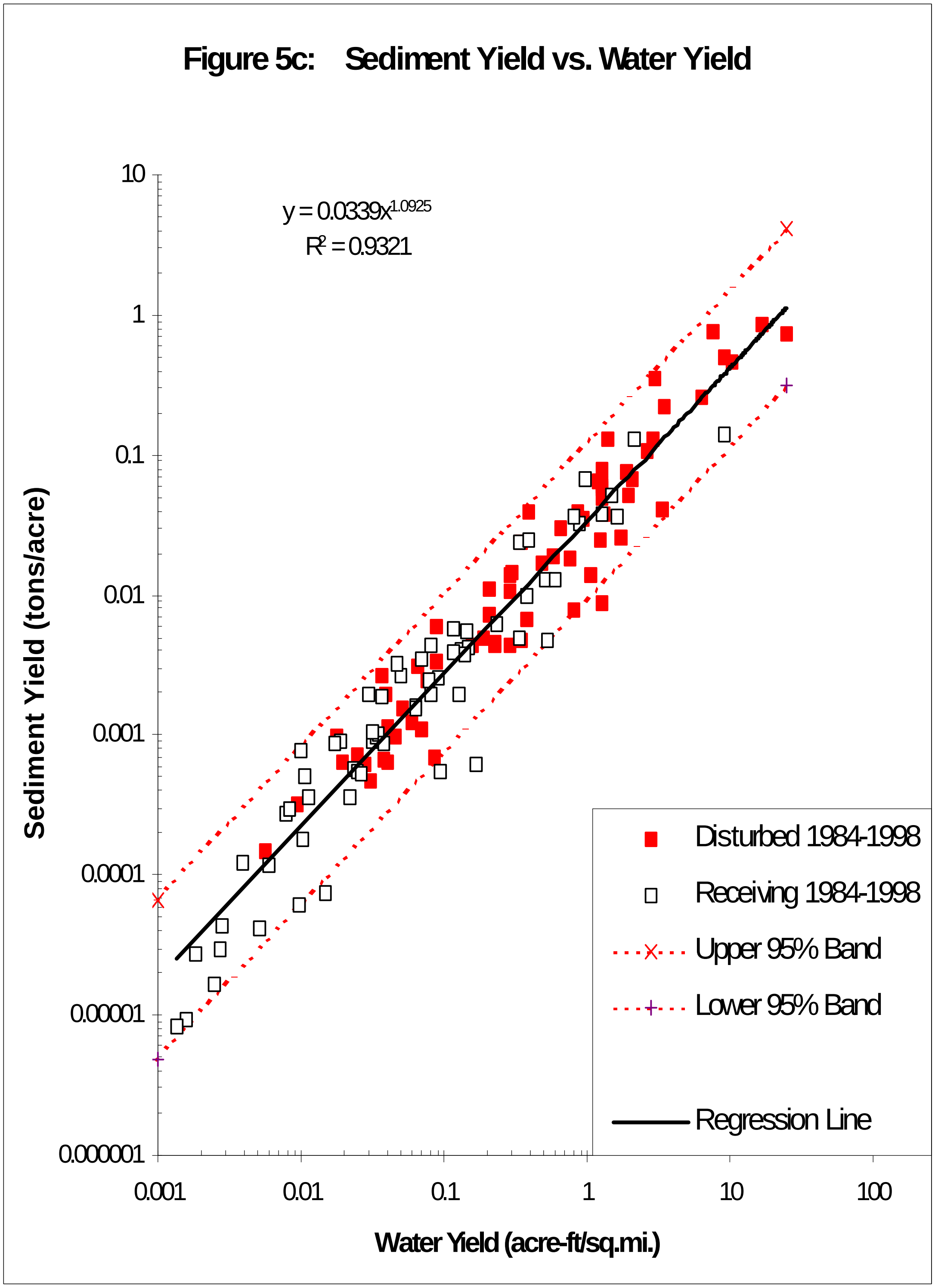


Figure 5c: Sediment Yield vs. Water Yield
y = 0.0339x^1.0925
R² = 0.9321
Sediment Yield (tons/acre)
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.001
0.01
0.1
1
10
100
Water Yield (acre-ft/sq.mi.)
Disturbed 1984-1998
Receiving 1984-1998
Upper 95% Band
Lower 95% Band
Regression Line

To confirm that the use of ASCs are effective, Bridger also conducts annual surveys of the receiving streams. For example, Bridger Coal Company has conducted an annual survey of Nine and One-Half Mile Draw since 1987. The surveys include up to nine cross sections used to model Nine and One-Half Mile Draw. Two cross sections are located upstream from the final highwall, three are located in the reclaimed reach, and four are located downstream from the boxcut disturbance limit. Areas of head cutting, aggradation, or degradation are noted and reported each year. Based on data available (up to 1992), no aggradation or degradation has been detected downstream of the disturbance in Nine and One-Half Mile Draw.

5.2.7 Summary

ASC technology is the primary means of sediment control at the Jim Bridger Mine. Ongoing surface water monitoring is used to detect the impact of mine disturbance treated with ASC techniques on receiving stream water quality. Analysis of monitoring results to date (1984-1998, Table 5g) has shown that, for storm events less than 10-year, 24-hour, background sediment levels have not been exceeded in disturbed watersheds. Analysis also has shown that sediment in disturbed watersheds correspond to sediment in receiving watersheds relative to sediment storage and release. These ASC design and monitoring methods have proven successful over a lengthy period of experimentation, evaluation, and application.

5.3 Case Study 3 (Water Engineering & Technology, Inc., 1990)

Case Study 3 summarizes a study performed for the Office of Surface Mining Reclamation and Enforcement during 1987-1989. This extensive project was jointly commissioned by the National Coal Association, the Office of Surface Mining Reclamation and Enforcement, BHP-Utah International Inc., Peabody Coal Company, and the Pittsburgh and Midway Coal Mining Company and was prepared by Water Engineering & Technology, Inc. Details of the project are provided in the "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West" (WET, Inc., 1990).

The study had four major objectives:

- Assess average annual background sediment yield at three mine sites based on surveying and computation of sediment accumulation in ponds;
- Evaluate available computer models for prediction of watershed runoff and sediment yield, and selection of the model that best represents these processes at semiarid mine sites;
- Evaluate runoff and erosion response to rainfall using rainfall simulation testing on test plots (12 feet wide by 35 feet long). Use resulting data and information to calibrate and validate the computer model selected; and
- Apply the model to evaluate alternative sediment control practices and the ability of such practices to maintain erosion from reclaimed lands at or below comparable background erosion levels.

The study targeted sedimentation and erosion conditions in semiarid coal regions using data and information collected at the at Navajo Mine near Farmington, New Mexico (BHP-Utah International, Inc.), McKinley Mine near Gallup, New Mexico (Pittsburgh & Midway Coal Company), and the Black Mesa Mine near Kayenta, Arizona (Peabody Coal Company). All three mines are located in a semiarid environment where sediment yield is large and variable. Erosion generally results from the occurrence of short duration, high intensity rainfalls.

5.3.1 Background Sediment Yield

Surveys were conducted in ponds located near the McKinley and Navajo Mines to determine average sediment yields from undisturbed, semiarid watershed basins. No suitable ponds were identified at the Black Mesa Mine.

Eight ponds were surveyed near the McKinley Mine. Measured sediment yields (sedimentation rate, tons/acre/year) ranged from 0.11 to 3.2 tons/acre/year. The average sediment yield was 1.16 tons/acre/year with a standard deviation of 1.13 tons/acre/year. The lowest value of sediment yield was measured in a pond corresponding to basins with low relief and low hillslope gradients (MCM-3). The highest values of sediment yield were measured in ponds corresponding to basins with incised channels (MCM-1, 2, and 8). Ten ponds were surveyed near the Navajo Mine. Measured sediment yields for the Navajo Mine ponds ranged from 1.56 to 16.00 tons/acre/year. The average sediment yield was 4.82 tons/acre/year with a standard deviation of 4.54 tons/acre/year.

Sediment volume, sediment density, and sedimentation rate results from basins located near the McKinley and Navajo Mines are presented in Table 5h. The high variability in sediment yields is thought to be attributed in part to the age of the ponds (from 8 to 38 years), size of the basin drainage areas (averages are 0.17 and 0.64 square miles for Navajo and McKinley Mines, respectively), and types of soil (clay, sandy loam, loam, sandy clay loam, and clay loam).

Table 5h: Measured Sediment Yields at Navajo and McKinley Coal Mines

Pond	Sediment Volume (ft^3)	Drainage Area (acres)	Age (years)	Sediment Density (lbs/ft^3)	Sedimentation Rate (tons/acre/yr)
NM-2	152,440	109	8	107	9.36
NM-3	115,060	183	8	100	3.93
NM-4	39,110	42.2	8	77.8	4.50
NM-5	25,140	57.6	8	82.6	2.25
NM-6	5,180	19.2	8	92.7	1.56
NM-7	55,440	71.6	8	60.6	2.93
NM-8	21,860	5.1	8	60.6	16.00
NM-9	25,390	64.0	8	87.1	2.16
NM-10	221,780	320	8	89.1	3.86
NM-11	113,710	192	15	82.3	1.62
MCM-1	175,690	89.6	33	68.9	2.05
MCM-2	220,100	110.2	34	72.7	2.13
MCM-3	71,000	570	33	58.5	0.11
MCM-4	137,830	211	33	68.5	0.68
MCM-6	120,310	580.4	38	81.0	0.23
MCM-7	105,770	173	37	71.5	0.59
MCM-8	642,370	224	36	79.4	3.16
MCM-9	154,350	509	31	69.4	0.34

NM = Navajo Mine
MCM = McKinley Mine

In general, sediment yields measured from the Navajo Mine basins were greater than those from the McKinley Mine basins. This observation has been attributed to the following factors:

- average drainage area for the Navajo Mine basins (0.17 square miles) is less than the average drainage area for basins at the McKinley Mine (0.64 square miles);
- drainage density is greater at the Navajo Mine basins (15.2 miles/square miles) than at the McKinley Mine basins (4.2 miles/square miles);
- the vegetation density is greater near the McKinley Mine basins (41 percent) than for basins near the Navajo Mine (15 percent); and
- the Navajo Mine basins have badland soil associations and none of the McKinley mine basins have badland soil associations.

The usefulness of this information for evaluation of background sediment yield is limited by several factors. First, the age of the the ponds was often uncertain and some may not have been in existence long enough to have received runoff and sediment resulting from large storm events that control watershed response in a semiarid environment. Second, reliable measurements of sediment yield can only be obtained if the ponds have not been breached or overtopped, and this information was not known. Third, ponds should be located in basins having geologic properties and morphometric (drainage area and density) properties similar to those of the mine watersheds. Some of the ponds near the McKinley mine did not meet this later condition and exhibited low rates of sediment yield possibly due to the presence of geologic controls in channels and watersheds (i.e., exposed bedrock). Finally, sediment yield in the semiarid west is largely governed by the occurrence of localized, relatively large storm events. Without accurate data describing the rainfall conditions in the watershed, it is difficult to compute a meaningful average annual sediment yield. It is difficult to determine if the sediment yield is the result of a single, rare storm event (i.e., 50-year storm) or the result of a sequence of smaller events. Lacking accurate rainfall data, pond sediment volumes could not be used to directly calibrate a computer model.

5.3.2 Evaluation of Watershed Computer Models

The second objective of the study was to assess available watershed hydrologic and sediment transport models to determine the model most appropriate for use in evaluation of alternative sediment control practices. Detailed evaluations were made of five models (Water Engineering & Technology, 1990):

- **ANSWERS** - Areal Nonpoint Source Watershed Environmental Response Simulation
- **KINEROS** - Kinematic Erosion Model
- **MULTSED** - Watershed and Sediment Runoff Simulation Model for Multiple Watersheds
- **PRMS** - Precipitation-Runoff Modeling System
- **SEDIMOT II/SEDCAD** version - Hydrology and Sedimentology Watershed Model II

Each model was evaluated with respect to:

- watershed representation;
- rainfall components;
- infiltration, interception and surface detention components;
- runoff components;
- sedimentation components;
- ease of file generation;
- performance with test data; and
- sensitivity analysis of the various inputs and parameters.

Rather than developing an artificial data set to test the models, a data set obtained from the USDA-ARS Sedimentation Laboratory, Oxford Mississippi for a 4.7 acre, severely eroding soybean field in northwest Mississippi was used. These data include nine events that occurred during the 1985-1986 growing season and represent a wide range of vegetation cover. Two of the nine events were relatively extreme (both of approximate 10-year return periods, one having a duration of two hours and the other having a duration of four hours). Accurate measurements of rainfall, runoff and sediment yield were available for each event at this site, and the topography of the field was surveyed in great detail. Although this data set does not represent coal mines in a semiarid environment, the processes of infiltration, runoff generation, soil detachment, sediment transport and deposition can be considered universal.

Results of computer model tests are presented in Table 5i. Five models were ranked from one (most accurate) to five (least accurate) for seventeen categories. Twelve categories deal with physical processes. The other categories are (1) watershed representation, (2) generalization of watershed reproduction, (3) ease in subdividing watersheds and generating watershed data, (4) ease in generating other data files, and (5) performance of the model with test data.

Table 5i: Ranking of Five Computer Models

Category	**ANSWERS**	**KINEROS**	**MULTSED**	**PRMS**	**SEDIMOT II**
Rainfall	P 2	P 2	P 2	P 4	S 5
Interception	P 3	P 3	P 1	P 3	S 5
Infiltration					
Hillslope	E 4	P 2	P 2	P 2	S 5
Channel	N 4	P 2	P 1	N 4	N 4
Runoff					
Hillslope	P 2	P 1	P 4	P 3	S 5
Channel	P 2.5	P 2.5	P 2.5	P 2.5	P-S 5
Detachment					
Hillslope	P? 2.5	P? 2.5	P? 2.5	P? 2.5	S 5
Channel	N 3	P? 2	P? 1	N 4.5	N 4.5
Transport					
Hillslope	P? 1.5	P? 3	P? 1.5	P? 4	S 5
Channel	P? 1.5	P? 3	P? 1.5	P? 4.5	E 4.5
Deposition					
Hillslope	P? 1	P? 2	N 4	N 4	N 4
Channel	P? 1.5	P? 3	P? 1.5	N 5	E 5
Watershed Representation					
Generality	1.5	1.5	4	4	4
Generation	5	3	3	3	1
Performance with Test Data	3	1.5	1.5	(1 to 5)	4
Data File Generation	4	2	3	5	1
Areas of Concern	2	3	1	5	4
Sum of Ranks	**44**	**39**	**37**	**(60 to 65)**	**70**
Number of First Ranks	**8**	**7**	**12**	**3**	**2**

E = Empirical Relationship; N = Not Simulated; P = Process Based; P? = Process Assumption
1 = Highest Rank; 5 = Lowest Rank

As a result of these analyses, the MULTSED model achieved the most number of first place scores. Therefore, MULTSED was selected for use in subsequent phases of this project.

5.3.3 Rainfall Simulation Data Collection

Rainfall simulation testing was conducted at the Navajo Mine during 1987 and 1988 and at the McKinley Mine during 1988 to measure and collect data regarding the following parameters:

- rainfall
- runoff
- sediment yield
- soil properties
- vegetation and cover densities

By testing paired plots (one plot to be used for model calibration and one to be used for model verification) and collecting data from two simulated rainstorms, four sets of data were obtained from each test site. Test sites encompassed a range of slopes, ages of reclamation and reclamation practices and included five test sites in undisturbed areas at each mine. The rainfall simulation testing program provided 76 data sets describing the rainfall-runoff-erosion process at the Navajo Mine (19 sites x 2 plots x 2 test runs) and 80 data sets at the McKinley Mine (20 sites x 2 plots x 2 test runs).

In addition, data were available for the Black Mesa Mine from 24 test plots (10-feet wide by 35-feet long) representing a range of slopes, surface treatments and watershed size (from 3 to 41 acres). Runoff and sediment yield generated by natural rainfall for Navajo Mine and McKinley Mine test plots and Black Mesa Mine watersheds were available for the period of 1983 to 1987. Tables 5j, 5k, and 5l contain a summary of the runoff and sediment yield information obtained from the Navajo, McKinley, and Black Mesa Mines, respectively.

Table 5j: Rainfall, Runoff and Sediment Yield Data for Navajo Mine

Plot	Storm Event Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
1	1	Right	2.5	1.42	27.0	8,690
	1	Left	2.2	0.72	6.7	4,240
	2	Right	2.6	2.02	36.8	8,320
	2	Left	2.6	2.08	33.0	7,260
2	1	Right	2.0	0.91	16.3	8,180
	1	Left	2.0	1.23	18.0	6,690
	2	Right	2.7	1.66	41.2	11,400
	2	Left	2.6	1.76	34.9	9,070
3	1	Right	2.0	0.75	10.1	6,210
	1	Left	2.7	0.85	13.0	6,970
	2	Right	2.1	1.31	32.4	11,300
	2	Left	2.4	1.31	30.0	10,500
4	1	Right	2.3	1.97	38.2	8,890
	1	Left	1.8	1.72	28.3	7,530
	2	Right	2.2	1.36	17.6	5,920
	2	Left	1.0	0.87	9.0	4,720
	3	Right	2.1	1.88	23.6	5,740
	3	Left	1.4	1.06	10.6	4,600
5	1	Right	2.0	0.28	0.8	1,310
	1	Left	2.3	0.71	1.4	922
	2	Right	2.7	0.90	6.1	3,110
	2	Left	2.2	0.98	5.4	2,530
6	1	Right	2.9	0.40	0.0	35
	1	Left	2.7	0.33	0.6	849
	2	Right	2.8	1.10	1.8	727
	2	Left	2.6	1.18	5.0	1,920
	3	Right	NDC	NDC	-	-
	3	Left	2.4	1.32	2.2	759
	4	Right	NDC	NDC	-	-
	4	Left	1.4	1.05	1.5	636

Plot	Storm Event Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
7	1	Right	2.3	0.50	0.3	283
	1	Left	2.2	0.81	0.4	238
	2	Right	2.6	0.68	0.6	281
	2	Left	2.3	1.14	0.6	224
8	1	Right	3.1	0.27	0.3	501
	1	Left	2.0	0.32	0.2	359
	2	Right	2.7	0.14	0.1	434
	2	Left	2.7	0.14	0.1	416
	3	Right	2.2	0.42	0.4	471
	3	Left	1.8	0.42	0.4	404
9	1	Right	2.3	1.32	209.0	72,500
	1	Left	2.7	0.53	244.8	73,200
	2	Right	2.4	2.26	341.1	68,900
	2	Left	2.2	1.89	240.8	58,300
10	1	Right	2.6	1.24	4.8	1,790
	1	Left	2.7	1.20	4.0	1,550
	2	Right	2.1	1.62	7.5	2,130
	2	Left	2.3	1.50	7.6	2,320
11	1	Right	2.3	1.12	6.9	2,800
	1	Left	2.2	1.02	11.5	5,160
	2	Right	2.4	1.68	22.5	6,150
	2	Left	2.0	1.29	19.2	6,800
12	1	Right	2.2	1.32	209.2	72,200
	1	Left	2.2	1.26	176.2	64,100
	2	Right	2.5	2.07	314.7	69,600
	2	Left	2.3	1.94	306.1	72,200
13	1	Right	2.4	0.00	0.0	0
	1	Left	2.2	0.00	0.0	0
	2	Right	2.7	0.41	0.8	866
	2	Left	2.4	0.44	1.0	1,050
14	1	Right	2.3	0.36	1.2	1,490
	1	Left	2.4	0.17	0.4	996

Plot	Storm Event Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
14	2	Right	2.2	1.66	11.8	3,240
	2	Left	2.6	1.58	9.6	2,790
15	1	Right	2.6	0.00	0.0	0
	1	Left	2.6	0.20	0.4	809
	2	Right	2.5	0.70	1.4	945
	2	Left	2.6	1.50	7.2	2,200
16	1	Right	2.5	0.55	1.6	1,380
	1	Left	2.6	0.47	2.2	2,100
	2	Right	2.9	2.51	5.5	1,010
	2	Left	2.9	2.56	6.1	1,080
17	1	Right	2.4	2.03	107.6	24,200
	1	Left	2.4	1.97	98.9	23,000
	2	Right	2.8	2.50	106.3	19,400
	2	Left	2.8	2.69	136.4	23,200
18	1	Right	2.3	0.63	0.8	569
	1	Left	2.0	0.28	0.2	396
	2	Right	2.5	1.24	2.3	849
	2	Left	2.5	1.30	1.4	496
19	1	Right	2.6	2.33	38.3	7,530
	1	Left	2.3	1.98	35.3	8,150
	2	Right	3.1	2.92	46.5	7,280
	2	Left	2.5	1.90	36.0	209.0

Table 5k: Rainfall, Runoff and Sediment Yield Data for McKinley Mine

Plot	Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
1	1	Right	1.9	0.09	0.6	3,150
	1	Left	2.8	0.98	6.2	2,880
	2	Right	3.0	0.81	6.3	3,550
	2	Left	2.4	1.05	6.0	2,630
2	1	Right	1.9	0.09	0.1	689
	1	Left	1.8	0.06	0.1	735
	2	Right	2.7	0.62	2.4	1,400
	2	Left	2.6	0.41	3.7	3,350
3	1	Right	2.8	0.74	4.1	2,520
	1	Left	2.1	0.61	18.8	14,000
	2	Right	3.0	1.43	8.2	2,610
	2	Left	1.8	0.77	4.6	2,750
4	1	Right	2.5	1.02	6.2	2,800
	1	Left	3.4	1.32	7.3	2,530
	2	Right	2.6	1.63	6.7	1,880
	2	Left	3.0	1.68	5.9	1,590
5	1	Right	3.6	1.40	15.1	4,940
	1	Left	3.2	0.87	13.8	7,240
	2	Right	3.1	1.74	14.6	3,830
	2	Left	2.9	1.09	12.2	5,100
6	1	Right	2.5	0.82	4.8	2,680
	1	Left	3.0	1.46	8.6	2,690
	2	Right	3.1	1.45	7.0	2,210
	2	Left	3.0	1.71	10.5	2,820
7	1	Right	3.1	0.53	0.5	322
	1	Left	2.9	0.012	0.04	1,530
	2	Right	2.4	0.98	0.5	184
	2	Left	3.3	1.28	2.8	923
8	1	Right	2.7	1.02	3.8	1,710

Plot	Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
8	1	Left	2.8	0.94	2.8	1,340
	2	Right	3.1	1.81	7.3	1,840
	2	Left	2.9	1.86	7.8	1,910
9	1	Right	2.3	0.46	1.9	1,910
	1	Left	3.1	0.81	8.2	4,640
	2	Right	2.8	1.13	8.4	3,420
	2	Left	2.9	1.02	12.6	5,650
10	1	Right	3.2	0.42	5.6	6,180
	1	Left	2.9	0.17	0.6	1,650
	2	Right	2.6	1.04	9.3	4,100
	2	Left	2.2	0.45	3.3	3.340
11	1	Right	3.1	0.89	19.5	10,010
	1	Left	3.4	1.44	39.1	12,470
	2	Right	3.2	2.05	44.2	9,850
	2	Left	2.5	1.66	31.2	8.580
12	1	Right	2.9	1.67	21.5	5,900
	1	Left	3.0	1.88	17.1	4,170
	2	Right	1.9	1.28	10.9	3,920
	2	Left	2.4	2.21	14.1	2,920
13	1	Right	2.3	0.74	12.0	7,430
	1	Left	3.1	0.98	32.3	15,050
	2	Right	2.5	1.27	19.4	6,980
	2	Left	2.6	1.41	31.5	10,230
14	1	Right	2.6	1.48	7.0	2,150
	1	Left	2.3	1.22	5.4	2,000
	2	Right	2.5	1.47	6.5	2,040
	2	Left	2.7	1.75	8.6	2,260
15	1	Right	2.4	1.65	7.1	1,960
	1	Left	2.5	1.46	8.3	2,610
	2	Right	2.3	2.00	9.3	2,120
	2	Left	3.1	2.19	10.9	2,280
16	1	Right	2.6	2.38	153.7	29,500

Plot	Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
16	1	Left	2.4	1.98	115.7	26,780
	2	Right	2.4	1.89	100.5	24,290
	2	Left	2.2	1.83	81.3	20,350
17	1	Right	3.0	0.35	4.8	6,330
	1	Left	2.8	0.55	9.6	7,960
	2	Right	3.0	0.90	6.0	3,070
	2	Left	3.4	1.09	13.3	5,550
18	1	Right	2.3	0.80	11.7	6,730
	1	Left	3.1	1.10	40.5	16,890
	2	Right	3.1	1.78	53.6	13,760
	2	Left	2.5	1.42	42.1	13,550
19	1	Right	2.7	0.99	3.0	1,320
	1	Left	2.7	0.57	2.0	1,420
	2	Right	2.7	1.90	4.9	1,130
	2	Left	3.3	1.90	4.8	1,050
20	1	Right	2.4	1.54	86.5	25,710
	1	Left	2.6	1.62	95.8	27,070
	2	Right	2.7	2.19	93.4	19,510
	2	Left	2.8	2.27	100.0	20,160

Table 5l: Rainfall, Runoff and Sediment Yield Data for Black Mesa and Kayenta Mines

Watershed	Run Date	Plot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
N2 Small	7-21-86	221	0.9	0.012	0.190	8,710
	8-31-86		0.5	0.162	4.391	14,900
	9-23-86		0.9	0.057	0.208	1,990
	7-30-87		0.6	0.195	1.709	4,810
	8-31-86	222	0.5	0.256	8.077	17,300
	9-23-86		0.9	0.103	1.172	6,260
	7-30-87		0.6	0.147	4.049	15,100
	7-21-86	223	0.9	0.005	0.012	1,360
	8-31-86		0.5	0.116	1.849	8,720
	7-30-87		0.6	0.067	0.282	2,330
	7-21-86	224	0.9	0.005	0.010	1,120
	8-31-86		0.5	0.094	0.796	4,630
	9-23-86		0.9	0.024	0.042	960
	7-30-87		0.6	0.068	0.275	2,230
N2 Large	8-31-86	225	0.5	0.161	3.049	10,400
	9-23-86		0.9	0.138	0.250	991
	8-31-86	226	0.5	0.184	4.538	13,500
	9-23-86		0.9	0.149	0.377	1,390
	7-30-87		0.6	0.219	1.418	3,560
J27	8-31-85	271	0.5	0.004	0.004	500
	9-11-85		0.3	0.010	0.002	107
	7-20-86		0.5	0.006	0.003	288
	9-23-86		1	0.010	0.003	156
	8-31-85	272	0.5	0.006	0.015	1,440
	9-11-85		0.3	0.010	0.008	442
	7-20-86		0.4	0.007	0.011	893
	9-23-86		1	0.010	0.067	3,720
	8-31-85	273	0.5	0.027	0.098	1,970
	9-11-85		0.3	0.007	0.010	876
	7-20-86		0.5	0.005	0.009	886

Watershed	Run Date	Plot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
J27 (cont.)	9-23-86		1	0.078	0.167	1,180
	8-31-85	274	0.5	0.008	0.013	984
	9-11-85		0.3	0.005	0.002	242
	9-23-86		1	0.049	0.089	997
	8-31-85	275	0.5	0.037	0.087	1,310
	8-31-85	276	0.5	0.017	0.026	848
	9-11-85		0.3	0.003	0.000	0
	9-23-86		1	0.047	0.095	1,110
J3	7-29-85	303	1	0.307	7.802	13,900
	9-11-85		0.6	0.100	0.455	2,490
	9-18-85		0.5	0.026	0.132	2,770
	8-29-86		0.2	0.015	0.155	5,850
	9-08-86		0.3	0.017	0.198	6,270
	8-08-87		0.9	0.030	0.390	7,130
	7-29-85	304	1	0.436	10.538	13,300
	9-11-85		0.6	0.118	0.512	2,390
	9-18-85		0.5	0.085	0.143	927
	8-29-86		0.2	0.015	0.153	5,650
	9-08-86		0.3	0.033	0.315	5,270
	8-08-87		0.9	0.102	1.160	6,230
	7-29-85	305	1	0.436	16.936	21,300
	9-11-85		0.6	0.176	1.529	4,760
	9-18-85		0.5	0.133	0.400	1,650
	8-29-86		0.2	0.048	0.847	9,730
	9-08-86		0.3	0.089	1.508	9,280
	8-08-87		0.9	0.176	4.009	12,500
	7-29-85	306	1	0.257	3.354	7,170
	9-11-85		0.6	0.024	0.098	2,270
	9-18-85		0.5	0.023	0.067	1,620
	8-29-86		0.2	0.026	0.318	6,700
	9-08-86		0.3	0.028	0.144	2,810
	8-08-87		0.9	0.101	0.861	4,690

Watershed	Run Date	Plot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
J3 (cont.)	7-29-85	307	1	0.163	3.755	12,700
	9-11-85		0.6	0.084	0.397	2,600
	9-18-85		0.5	0.024	0.067	1,530
	8-29-86		0.2	0.006	0.019	1,900
	7-29-85	308	1	0.180	4.953	15,100
	9-11-85		0.6	0.080	0.879	6,020
	9-18-85		0.5	0.024	0.163	3,760
	8-08-87		0.9	0.028	1.097	21,300
N6	9-18-85	261	0.4	0.023	0.407	9,510
	9-23-86		0.8	0.074	0.445	3,290
	9-18-85	262	0.4	0.018	0.060	1,820
	9-23-86		0.8	0.072	0.330	2,540
	9-18-85	263	0.4	0.003	0.006	1,190
	7-21-86		0.6	0.012	0.037	1,670
	9-08-86		0.9	0.191	1.200	3,450
	9-23-86		0.8	0.090	0.144	884
	9-18-85	264	0.4	0.017	0.034	1,090
	7-21-86		0.6	0.017	0.060	1,900
	9-08-86		0.9	0.106	1.219	6,310
	9-23-86		0.8	0.115	0.750	3,570
	9-18-85	265	0.4	0.006	0.012	1,130
	7-20-86		0.5	0.005	0.032	3,880
	7-21-86		0.6	0.028	0.218	4,200
	9-23-86		0.8	0.045	0.132	1,610
	9-18-85	266	0.4	0.010	0.018	993
	7-20-86		0.5	0.005	0.019	1,980
	7-21-86		0.6	0.018	0.135	4,110
	9-23-86		2.5	0.039	0.103	1,440

5.3.4 Calibration and Validation of the MULTSED Model

The first step in the application of MULTSED for prediction ofrunoff and sediment yield involved calibration and validation of the model using the data collected from the Navajo, McKinley, and Black Mesa/Kayenta mines. One-half of the simulated rainfall test plot data were used for calibration and determination of appropriate infiltration and soil detachment coefficients. Following calibration, the MULTSED model was run using the calibrated infiltration and detachment coefficients to predict sediment yield and mean sediment concentration. Finally, total runoff, sediment yield, and mean sediment concentration predicted by MULTSED were compared to the remaining half of the simulated rainfall test plot data and to the available Black Mesa/Kayenta Mine data. Model verification determined that runoff amounts were predicted with the greatest accuracy, followed by mean concentration, and sediment yields.

Model results also showed a tendency for the model to over predict sediment and runoff rates for low flow conditions should not be of major concern because long-term erosion rates generally are dominated by extreme conditions when large magnitude runoff volumes occur. However, when predicting the runoff and sediment responses of various erosion control alternatives, the model should not be used for small storms that produce small amounts of runoff (< 0.5 inches).

5.3.5 Evaluation of Alternative Sediment Control Techniques

Successful calibration and validation of the MULTSED model provided a means to evaluate the effectiveness of alternative sediment control techniques relative to background conditions. To make these comparisons, a procedure was developed that uses rainfall depth-duration information available from National Oceanic and Atmospheric Administration (NOAA) Atlases at each mine site. Rainfall data describing storm events with recurrence intervals of 2, 5, 10, 25, 50, and 100 years were used to develop hypothetical storm distributions. MULTSED was then used to determine the runoff and sediment generated from a hill slope for this range of storm events.

Comparison were made between background sediment yield and predicted sediment yields associated with alternative sediment control techniques. Average annual sediment yield was computed using a probability weighting procedure that uses an incremental probability of occurrence of the aforementioned sequence of storms. Since the average value computed using this procedure is based on a broad range of storm events, it is expected to represent a reasonable long-term average. It should be noted that, depending on the sequence of storm events that actually occur, sediment yield within any given year could significantly deviate from this average value. For purposes of comparison, however, this calculation procedure provides a reasonable value for sediment yield.

Modeling was performed to evaluate sediment yield response to variations in slope length, slope gradient, cover density, and the presence or absence of furrows (depression storage) on the reclaimed surface. The results agreed with expectations: sediment yield increases with increasing plot slope gradient and slope length, decreases with increasing vegetative cover, and decreases with increased depression storage. Model prediction results for the sediment yield response to ASCs at the Navajo Mine, McKinley Mine, and Black Mesa/Kayenta Mine are presented in Figures 5d through 5q.

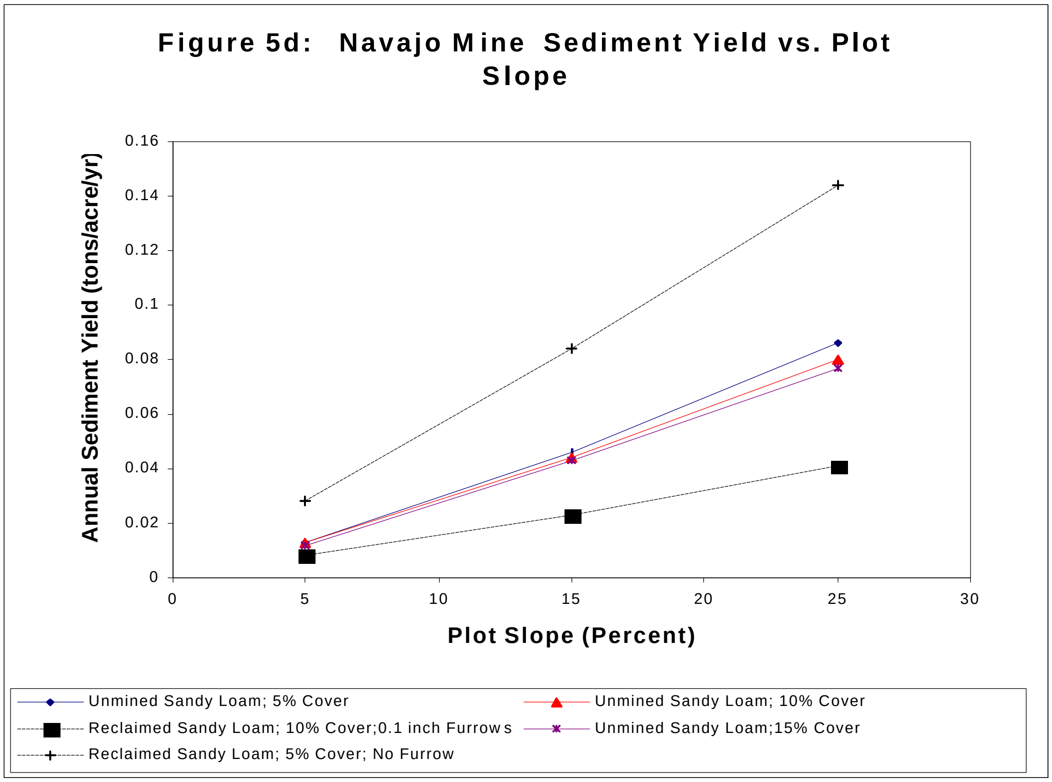


Figure 5d: Navajo Mine Sediment Yield vs. Plot Slope
Annual Sediment Yield (tons/acre/yr)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
Plot Slope (Percent)
Unmined Sandy Loam; 5% Cover
Unmined Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover;0.1 inch Furrows
Unmined Sandy Loam;15% Cover
Reclaimed Sandy Loam; 5% Cover; No Furrow

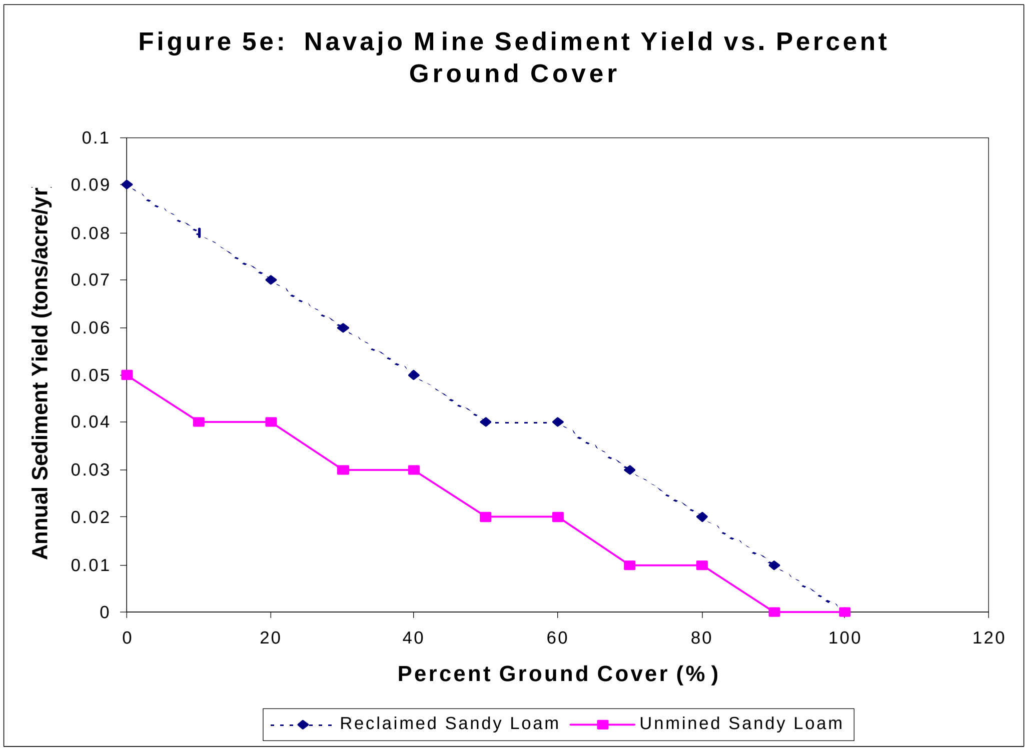


Figure 5e: Navajo Mine Sediment Yield vs. Percent Ground Cover
Annual Sediment Yield (tons/acre/yr
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
20
40
60
80
100
120
Percent Ground Cover (%)
Reclaimed Sandy Loam
Unmined Sandy Loam

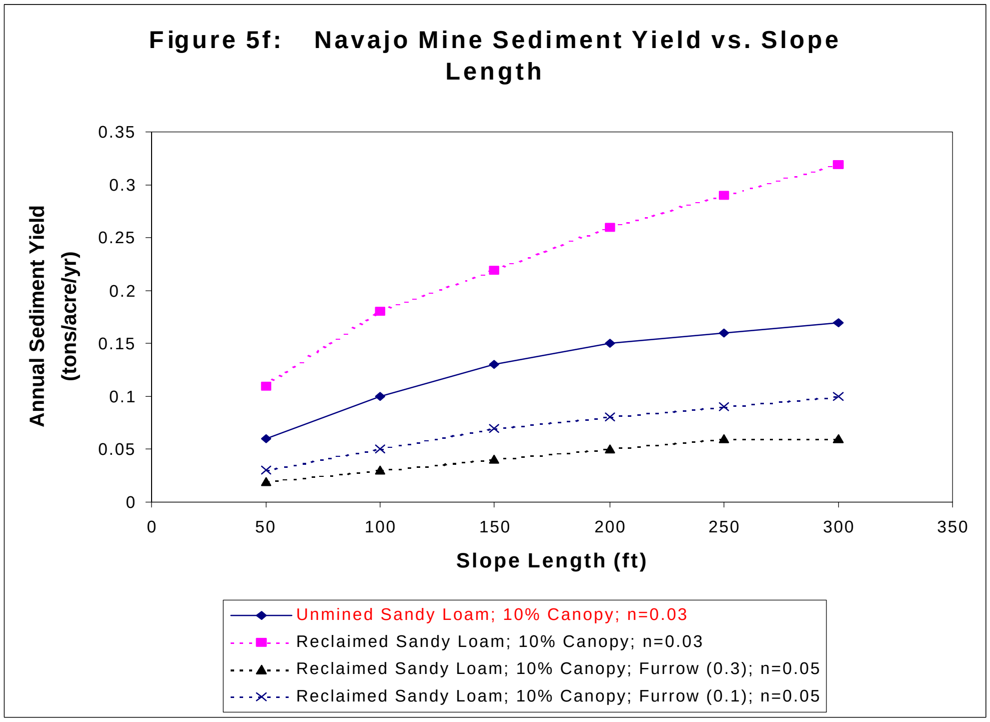


Figure 5f: Navajo Mine Sediment Yield vs. Slope Length
Annual Sediment Yield (tons/acre/yr)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
Slope Length (ft)
Unmined Sandy Loam; 10% Canopy; n=0.03
Reclaimed Sandy Loam; 10% Canopy; n=0.03
Reclaimed Sandy Loam; 10% Canopy; Furrow (0.3); n=0.05
Reclaimed Sandy Loam; 10% Canopy; Furrow (0.1); n=0.05

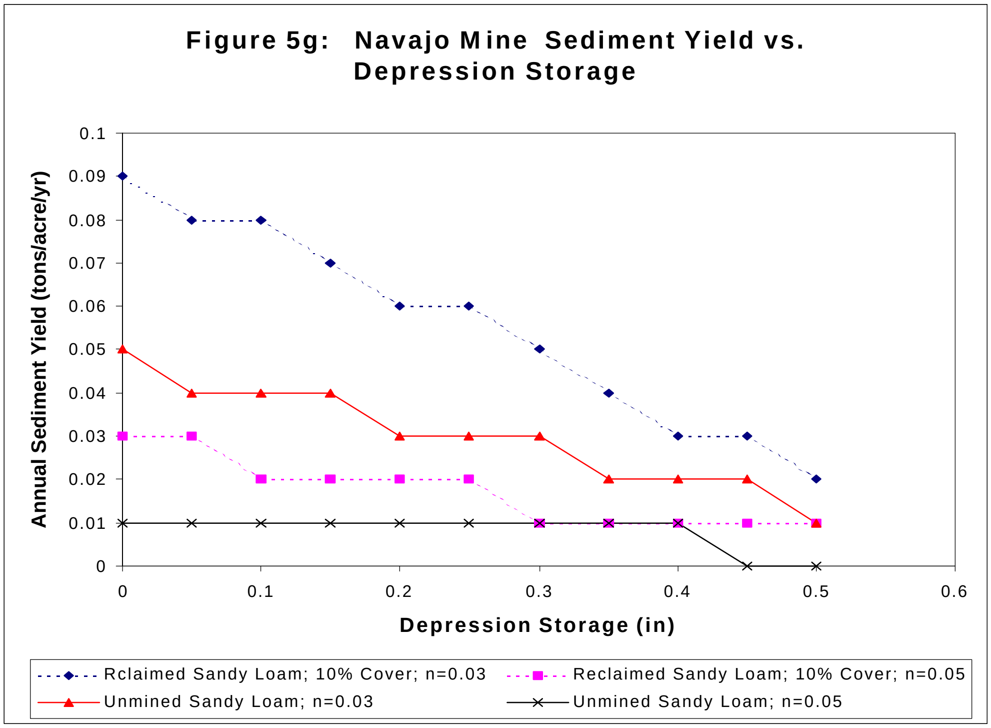


Figure 5g: Navajo Mine Sediment Yield vs. Depression Storage
Annual Sediment Yield (tons/acre/yr)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Depression Storage (in)
Rclaimed Sandy Loam; 10% Cover; n=0.03
Reclaimed Sandy Loam; 10% Cover; n=0.05
Unmined Sandy Loam; n=0.03
Unmined Sandy Loam; n=0.05

Figure 5h: McKinley Mine Sediment Yield vs. Plot Slope

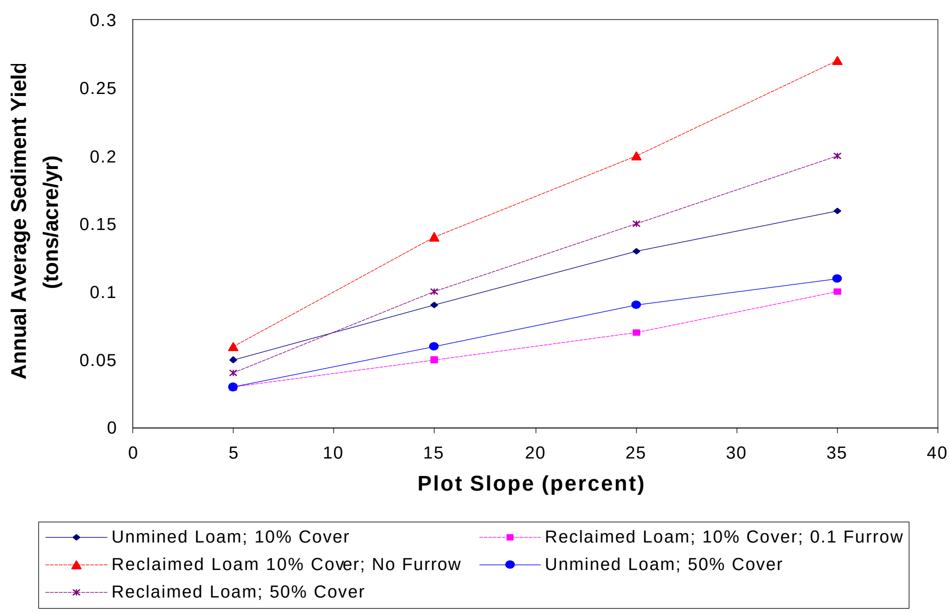
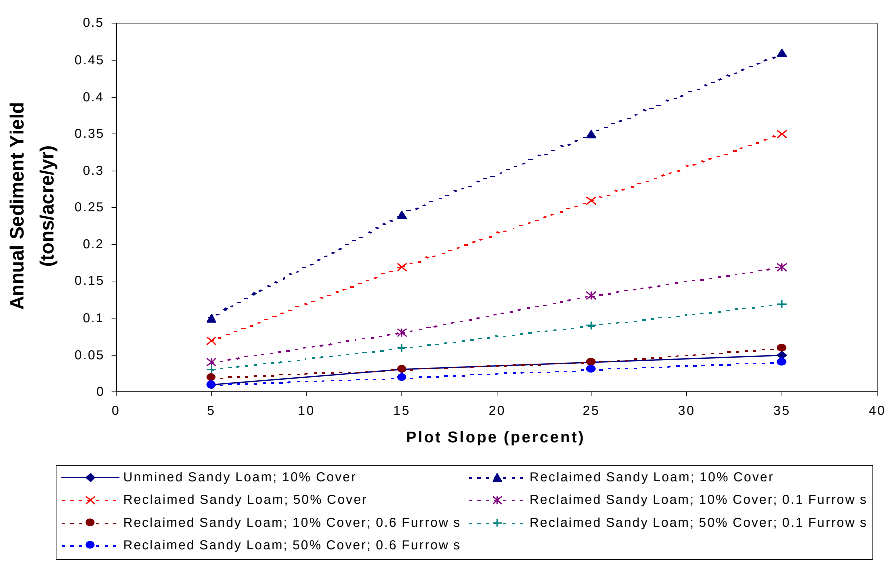


Figure 5i: McKinley Mine Sediment Yields vs. Plot Slope



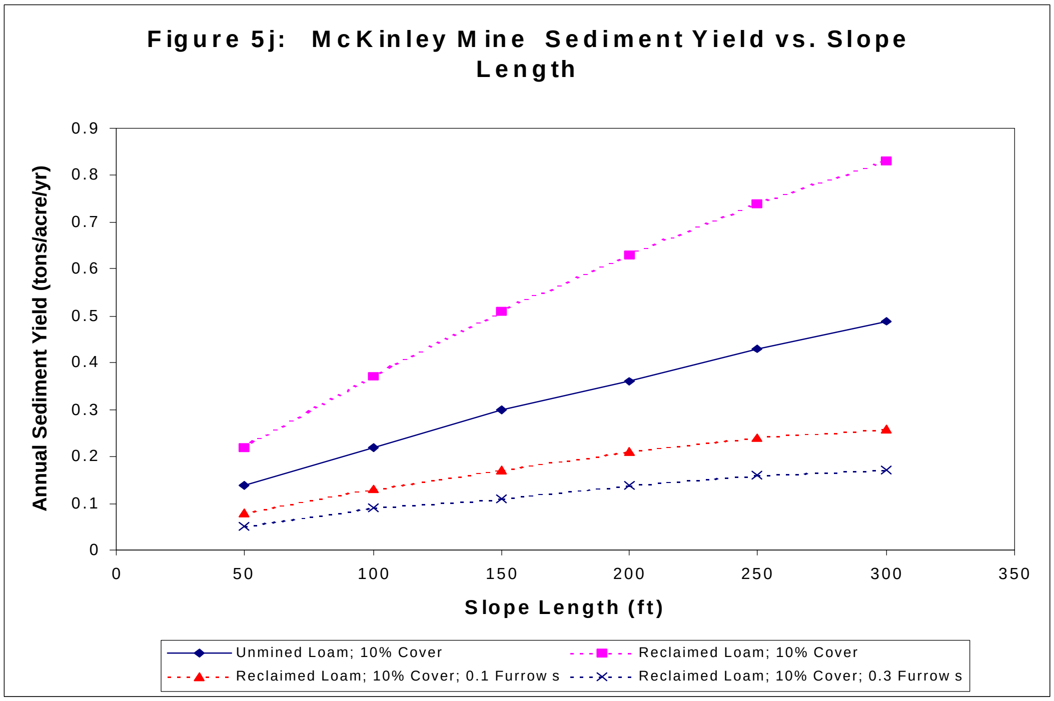


Figure 5j: McKinley Mine Sediment Yield vs. Slope Length
Annual Sediment Yield (tons/acre/yr)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Slope Length (ft)
Unmined Loam; 10% Cover
Reclaimed Loam; 10% Cover
Reclaimed Loam; 10% Cover; 0.1 Furrow s
Reclaimed Loam; 10% Cover; 0.3 Furrow s

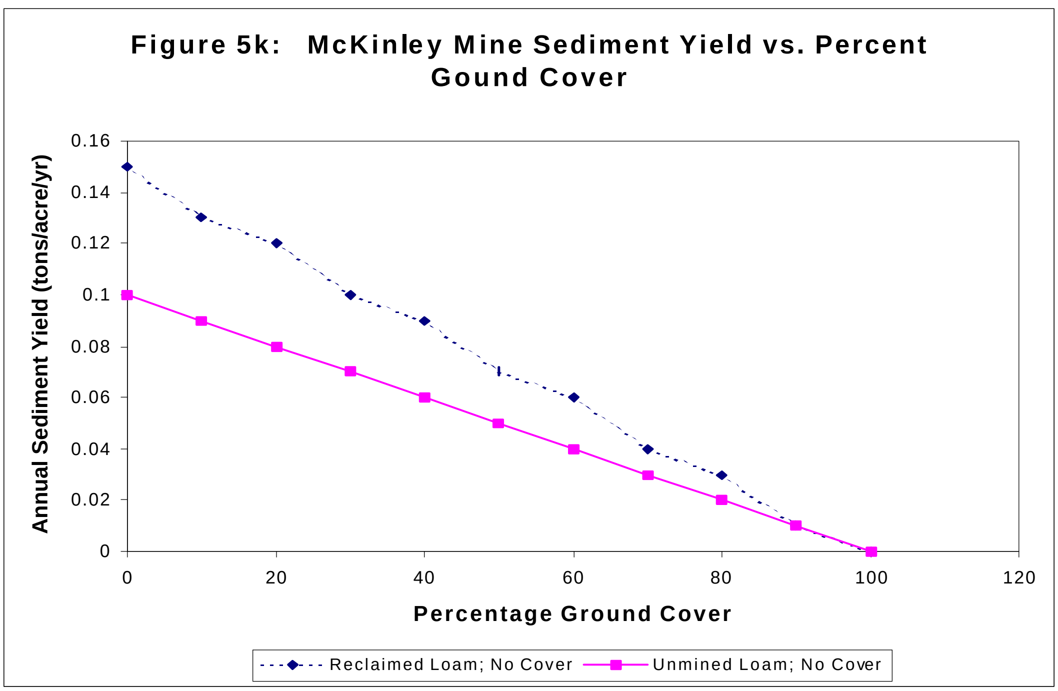


Figure 5k: McKinley Mine Sediment Yield vs. Percent Gound Cover
Annual Sediment Yield (tons/acre/yr)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20
40
60
80
100
120
Percentage Ground Cover
Reclaimed Loam; No Cover
Unmined Loam; No Cover

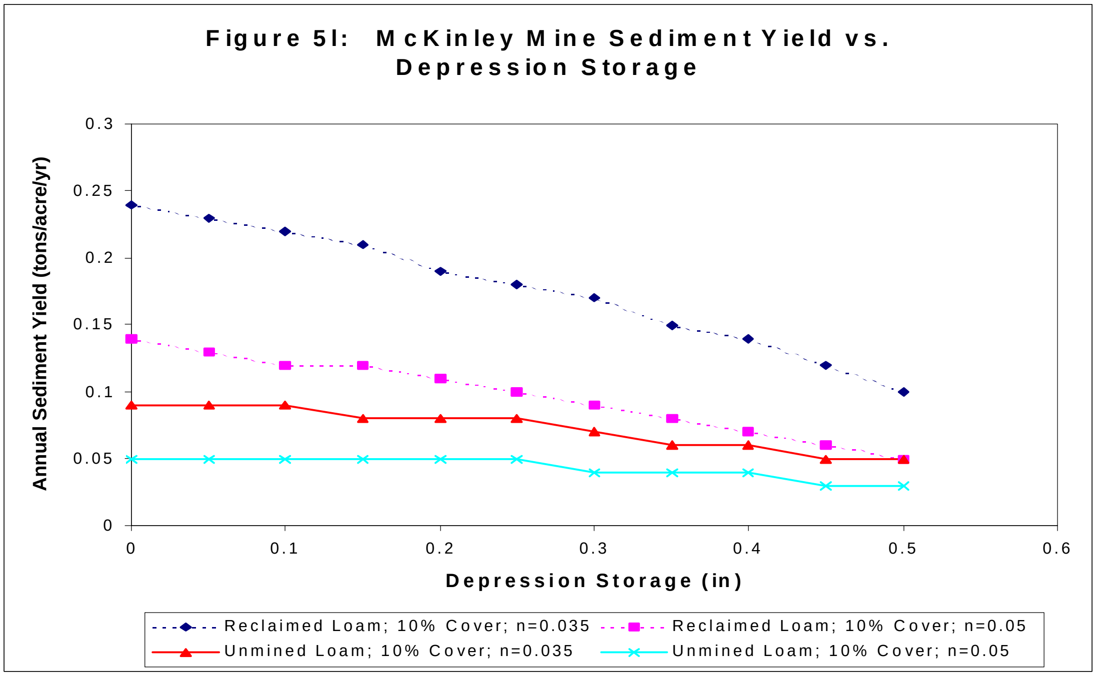


Figure 5l: McKinley Mine Sediment Yield vs. Depression Storage
Annual Sediment Yield (tons/acre/yr)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Depression Storage (in)
Reclaimed Loam; 10% Cover; n=0.035
Reclaimed Loam; 10% Cover; n=0.05
Unmined Loam; 10% Cover; n=0.035
Unmined Loam; 10% Cover; n=0.05

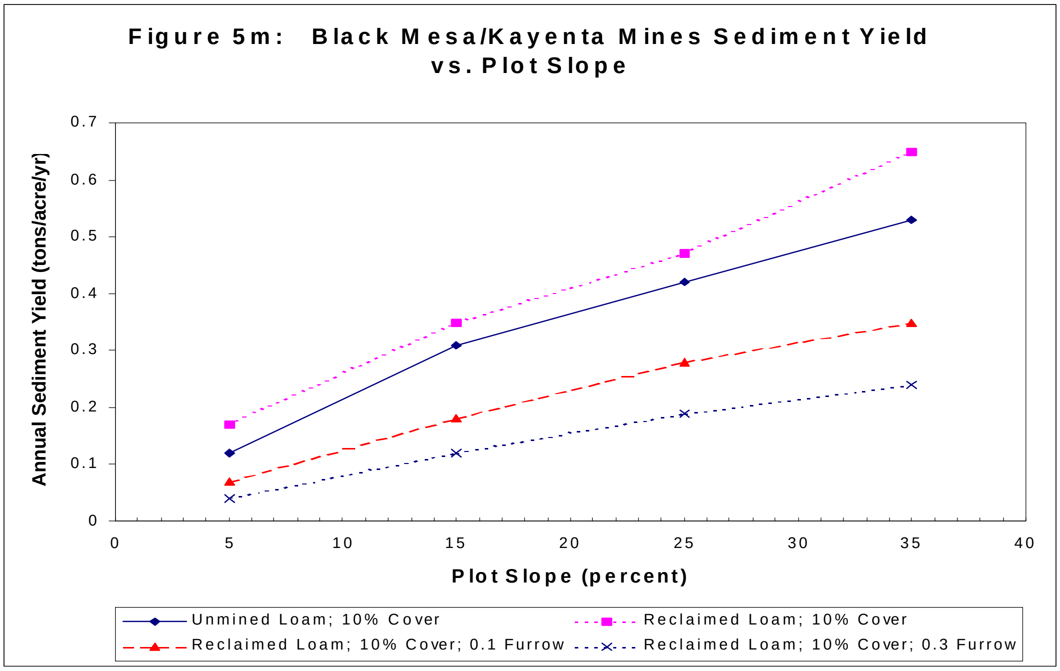


Figure 5m: Black Mesa/Kayenta Mines Sediment Yield vs. Plot Slope
Annual Sediment Yield (tons/acre/yr)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
Plot Slope (percent)
Unmined Loam; 10% Cover
Reclaimed Loam; 10% Cover
Reclaimed Loam; 10% Cover; 0.1 Furrow
Reclaimed Loam; 10% Cover; 0.3 Furrow

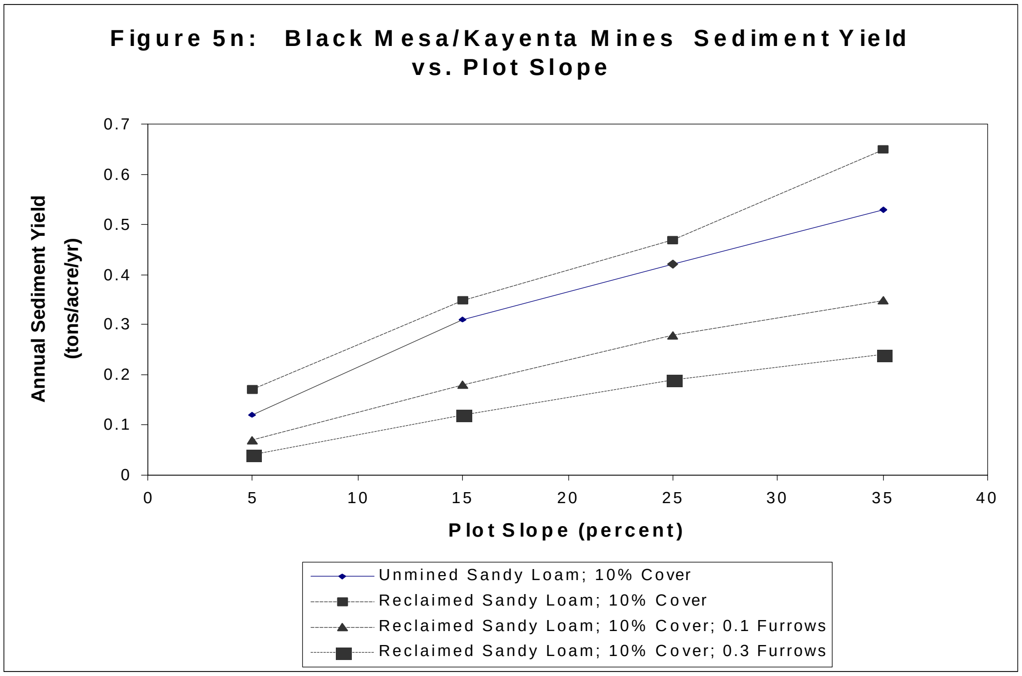


Figure 5n: Black Mesa/Kayenta Mines Sediment Yield vs. Plot Slope
Annual Sediment Yield (tons/acre/yr)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
Plot Slope (percent)
Unmined Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover; 0.1 Furrows
Reclaimed Sandy Loam; 10% Cover; 0.3 Furrows

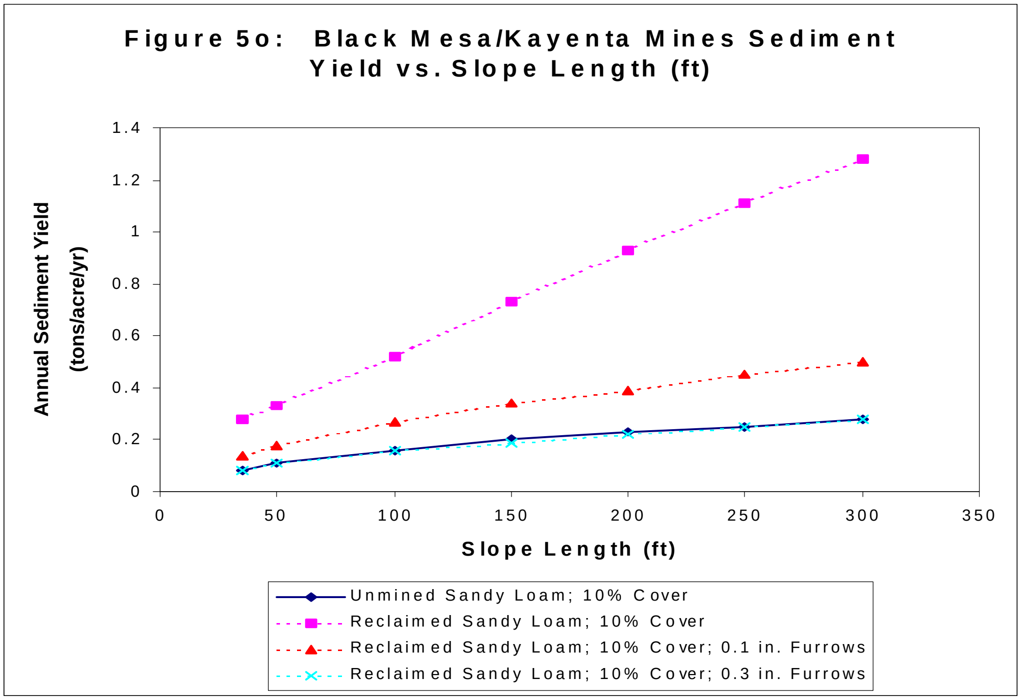


Figure 5o: Black Mesa/Kayenta Mines Sediment Yield vs. Slope Length (ft)
Annual Sediment Yield (tons/acre/yr)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
Slope Length (ft)
Unmined Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover; 0.1 in. Furrows
Reclaimed Sandy Loam; 10% Cover; 0.3 in. Furrows

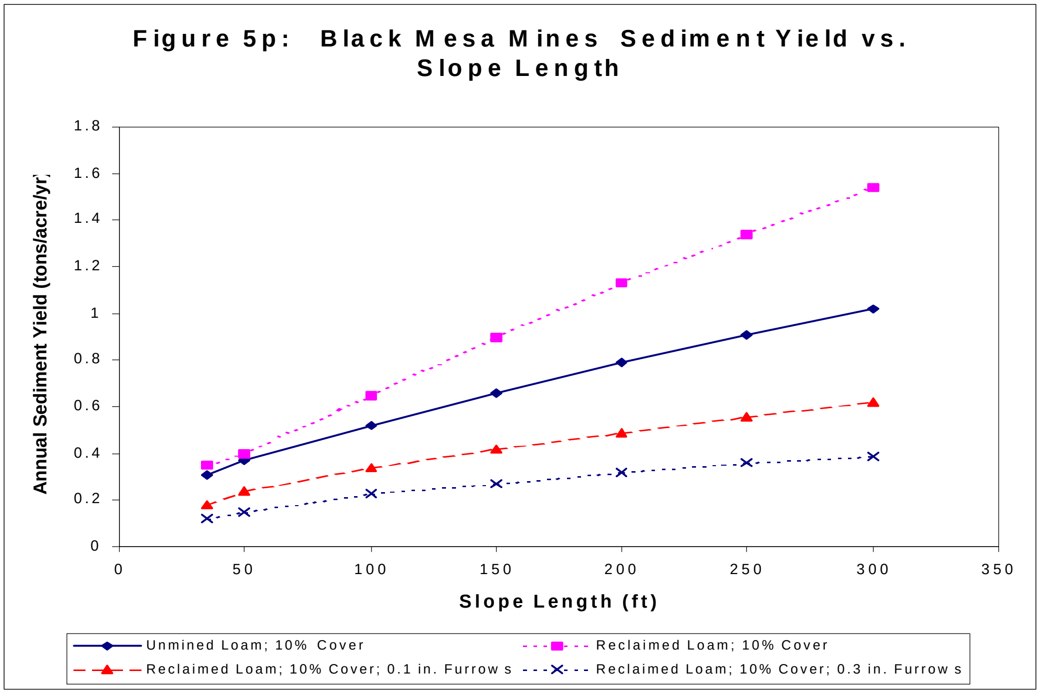


Figure 5p: Black Mesa Mines Sediment Yield vs. Slope Length
Annual Sediment Yield (tons/acre/yr)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
50
100
150
200
250
300
350
Slope Length (ft)
Unmined Loam; 10% Cover
Reclaimed Loam; 10% Cover
Reclaimed Loam; 10% Cover; 0.1 in. Furrows
Reclaimed Loam; 10% Cover; 0.3 in. Furrows

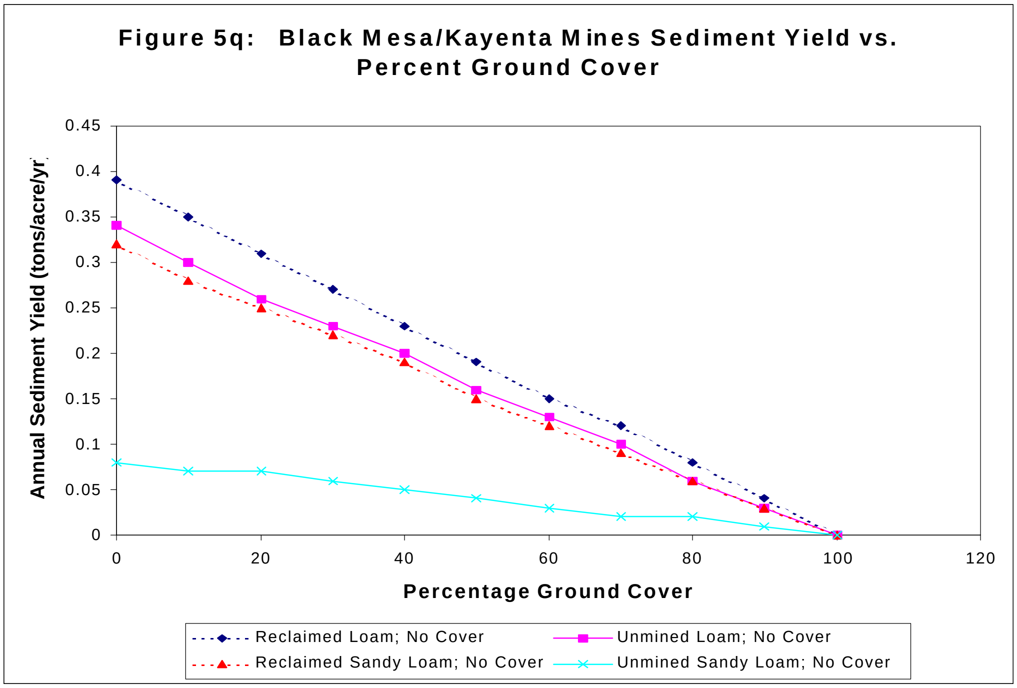


Figure 5q: Black Mesa/Kayenta Mines Sediment Yield vs. Percent Ground Cover
Annual Sediment Yield (tons/acre/yr)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0
20
40
60
80
100
120
Percentage Ground Cover
Reclaimed Loam; No Cover
Unmined Loam; No Cover
Reclaimed Sandy Loam; No Cover
Unmined Sandy Loam; No Cover

5.3.5.1 Navajo Mine

Model prediction results indicate that alternate sediment controls can be used to produce sediment yields that are less than background or unmined conditions. For example, an unmined sandy loam of 15 percent slope and 10 percent vegetative cover density produces more sediment than a reclaimed sandy loam of 25 percent slope and a 5 percent vegetative cover density if furrows capable of retaining 0.1 inch of rainfall are present and slope lengths are equal (Figure 5d). It is important to note that these furrows are only a temporary measure and a more permanent reclamation technique should be implemented. An example of this would be using rock or mulch as a ground cover.

Figure 5d also provides a comparison of pre-and postmined sandy loams. The figure indicates that reclaimed sandy loams (postmined) with vegetation (5 percent cover) but without furrows results in higher sediment yields than unmined areas of similar soil/sand cover for any slope. Figure 5d also indicates that achievement of background sediment yields solely through manipulation of slope gradient requires that the reclaimed slope gradient be significantly reduced. For example, to maintain a reclaimed sediment yield comparable to that of an unmined sandy loam on a 10 percent slope, the reclaimed slope not exceed 5 percent.

The effects of varying ground cover on sediment yield for sandy loams are shown in Figure 5e. A reclaimed sandy loam site would require significantly more ground cover to produce the same sediment yield as an unmined sandy loam site. For example, a reclaimed sandy loam soil, with at least 60 percent ground cover would yield approximately the same amount of sediment as unmined sandy soil with 20 percent ground cover.

Figure 5f provides a comparison of sediment yields from pre- and postmined sandy loam sites based on slope lengths. Based solely on slope length, reclaimed slope lengths should be less than 50 feet to maintain background sediments yields for an unmined sandy loam site with an original slope length of 100 feet.

Figure 5g illustrates the effectiveness of furrows in reducing hillslope sediment yield.

Surfaces with furrows tend to be rougher and therefore have higher Manning's n values than surfaces without furrows. For computer modeling purposes, plots without furrows were given a Manning's n of 0.03 and plots with furrows were given values of 0.05.

5.3.5.2 McKinley Mine

Similar to the Navajo Mine computer prediction results, Figure 5h shows that a significant reduction in reclaimed slope gradient is required to maintain sediment yield below background levels. Figure 5h also shows that reclaimed loam soil with 10 percent canopy cover and furrows capable of retaining 0.1 inch of rainfall produces less sediment than an unmined loam soil with 50 percent canopy cover. Figure 5i indicates that reduction of slope gradient by itself would not be sufficient to reduce sediment yield below background levels with a sandy loam soil at the McKinley Mine. A reclaimed sandy loam soil with a 50 percent canopy cover and furrows capable of retaining 0.6 inches of rainfall will produce less sediment than an unmined sandy loam with 10 percent canopy cover.

The average annual sediment yield for reclaimed loam soils also was compared to background conditions for different slope lengths, percentages of ground cover and amounts of depression storage as shown in Figures 5j, 5k, and 5l. Figure 5j shows that a 300-foot long reclaimed loam soil plot, with furrows capable of holding 0.1 inches of rainfall, produces less sediment than an unmined 150-feet long loam soil plot. Figure 5k illustrates that a reclaimed loam soil with at least 60 percent ground cover will yield approximately as much sediment as an unmined loam soil with 40 percent ground cover. Figure 5l shows the effect of depression storage and roughness on annual sediment yield. Reclaimed soils are much more sensitive to the amount of depression storage than unmined soils. Also as can be seen from 5l, a loam soil can be temporarily reclaimed to meet the background sediment yield of an unmined loam soil with 0.1 inch of depression storage (n = 0.035).

5.3.5.3 Black Mesa/Kayenta Mines

Figures 5m and 5n show the sediment yield response of a loam soil and sandy loam soil to changes in slope gradient for both pre- and post mine conditions, respectively. Both figures show that a modest 3 to 5 percent reduction in slope gradient can maintain sediment yields at or below background levels. Also shown in both figures are the effects of contour furrows on sediment yield. Figure 5m shows that reclaiming loam soil with furrows that are capable of retaining at least 0.1 inch of rainfall will satisfy the requirement of producing less sediment than the amount produced by background conditions. Reclaimed sandy loam soil requires furrows capable of retaining 0.5 inches of rainfall to meet the background criteria as shown in Figure 5n.

Figures 5o and 5p show the same results as Figures 5m and 5n except for slope length instead of plot slope. Figure 5o shows that for sandy loam soils, decreasing the slope length of the reclaimed area and reclaiming with furrows may be necessary to meet background sediment yields.

As shown in Figure 5q, for reclamation of loam and sandy loam soils that originally had 20 percent ground cover with rock mulch, a 30 percent ground cover and a 80 percent ground cover would be necessary for the loam and sandy loam soils respectively.

5.3.5.4 Conclusions

Comparisons were made between the erosion potential of reclaimed land versus undisturbed hillslope surfaces. In general, results of this evaluation tend to indicate that erosion potential of reclaimed surfaces exceeds that of unmined lands, when all other conditions are held constant. The addition of contour furrows to the land surface tends to significantly reduce erosion potential, however such features generally last only a few years. Contour furrows can also tend to hinder seeding and revegetation efforts.

More permanent forms of alternative sediment control practices include:

- manipulation of the slope gradient,
- manipulation of slope length,
- modification of the density of surface cover (vegetation, mulch, etc.),
- alteration of the hillslope surface to increase roughness or depression storage, and
- enhancement of infiltrative capacity of the soil.

Evaluation of the first four sediment control alternatives listed above shows that these alternatives generally can be used to meet the background performance standard. Depending on the specific properties of any particular site, defined by such variables as hillslope gradient and length, cover density, soil particle size distribution and infiltration capacity, one or more of these measures may be required for alternative sediment control to be effective. According to this study, the recommended procedure for evaluation of alternative sediment control requires use of the MULTSED model to define the background conditions of runoff and sediment yield for a range of storm conditions. Modeling of the reclaimed conditions then indicates the relative differences in runoff/erosion response resulting from mining activities. If postmine erosion exceeds the undisturbed erosion potential, MULTSED can be applied to evaluate the necessary modifications to the watershed system to meet the background performance standard.